World Electric Vehicle Journal

MDPI

Article

Evaluating the Barrier Effects of Charge Point Trauma on UK Electric Vehicle Growth

Keith Chamberlain * and Salah Al Majeed

School of Computer Science, College of Science, University of Lincoln, Lincoln LN67TS, UK; SAlMajeed@lincoln.ac.uk
* Correspondence: keith.c@me.com

Abstract: For electric vehicles (EVs) to realise the UK government's goal of mass-market dominance, there are surmountable hurdles to resolve before car users accept this radical shift in motoring technology. This study focuses on recent EV adopters who experience a new phenomenon described as charge point trauma (CPT). In contrast to range anxiety, we define CPT as the psychological, physiological, and behavioural condition where EV user's experiences develop trauma or anxiety in response to the availability of sufficient charge points, locations, payment processes, and operability. Resolving impediments to EV usage reduces long-term growth barriers, which we argue can subsequently lower or even eliminate EV driver anxiety. We conclude that range anxiety still plays a major part in overall EV driver trauma, and after deep analysis of our case study data conclude that a trauma other than range anxiety exists at the charge point. To mitigate this phenomenon, we propose a regulatory framework comprising a series of stimuli to encourage EV uptake. These recommendations should be targeted at regulating a new generation of EV charging stations to meet operational parity with current fossil fuel filling stations by ensuring they are always on, available in sufficient numbers, accessible and operable as part of the UK motorway and major trunk network. This will de-risk EV purchasing and stimulate their adoption in this embryonic stage, reducing CPT in the process.

Keywords: EV charger availability; electrical vehicles; barriers to EV adoption; EV user anxiety

check for updates

Citation: Chamberlain, K.; Al Majeed, S. Evaluating the Barrier Effects of Charge Point Trauma on UK Electric Vehicle Growth. *World Electr. Veh. J.* **2021**, *12*, 152. https://doi.org/10.3390/wevj12030152

Academic Editor: Aritra Ghosh

Received: 14 June 2021
Accepted: 6 September 2021
Published: 9 September 2021

1. Introduction

EVs are often depicted as the panacea to air pollution reduction toward a zero-carbon future. To prove its intent and commitment to carbon reduction, the UK government has accelerated its plan to ban all diesel and EVs from 2040 to 2030. Many EV growth barriers require resolution before the government's ambitious goal can be realised. As increased EV battery range lowers range anxiety amongst new and existing EV users, consumer's current fears point to the absence of sufficient charging infrastructure for EVs, particularly rapid chargers located on main motorway and trunk roads. Rapid charge point availability and geographic location concerns are cited as the leading barrier to the growth of EV purchases and user satisfaction in the UK [1]. EV development in the UK is significant due to growing consumer demand. However, the UK market lacks extensive investigation [2] since most EV research focuses on the USA and China-based [3] markets. This UK centric investigation will concentrate on motorway rapid chargers, the lifeblood for EV drivers partaking in long-range commuting.

We consider whether electric vehicle (EV) drivers suffer from a broader traumatic phenomenon than the established psychological experience of range anxiety. We hypothesise that a new source of distress or trauma is emerging that does not simply focus on an EV's range but extends to user apprehension and resulting behaviour. Primary causes include rapid charger location, availability, disparate payment processing, variable charge costs and general operability. In contrast, we contend that these impediments are seldom experienced by ICE (Internal Combustion Engine) drivers.

1.1. Defining Elements and Theoretical Framework

This study focuses on new and existing EV adopters who may experience this emerging phenomenon that we describe as CPT. In addition to the highly cited phenomenon of range anxiety [4–6], we define CPT as the psychological, physiological, and behavioural condition where EV user's experiences and anxiety vary in response to the availability, location, payment process and operability of an EV public rapid charge point. We argue that resolving these five significant obstacles to EV use reduces long-term barriers to sector growth, thus stimulating a decline in CPT, illustrated in Figure 1. Although not grouped as a collective phenomenon named CPT, these five EV driver anxieties are investigated in recent research [7].

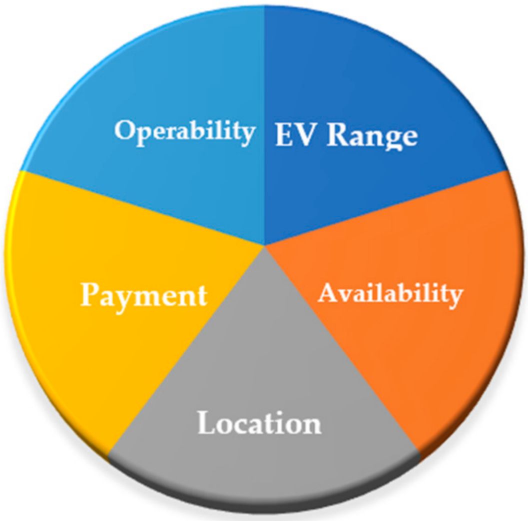

Figure 1. Five significant EV driver anxieties.

Whilst range anxiety is well-defined over the past decade, to date, no study has explicitly looked at CPT, a new phenomenon that is closely tied to all five elements in Figure 1 and is validated by research in a recent peer-reviewed survey [7] that is the first study to investigate four of the five elements, forming this new phenomenon that we specify as CPT.

Creating a theoretical framework to define a broad relationship between the established range anxiety phenomenon and CPT is fundamental. To illustrate these two distinct phenomena, we establish that range anxiety occurs en route, and CPT develops at the charging location. Figure 2. Illustrates the interrelationship between range anxiety and CPT and defines the boundaries between both phenomena. One of the four elements that contribute to CPT, the location of the charge point, is additionally a critical variable that contributes to range anxiety, illustrated in Figure 2. In Section 3, we analyse the results of our seven case studies, revealing range anxiety as a common thread running throughout the data that played a significant part in raising trauma levels before arriving at the charge point, despite the extended range of the EV employed in our investigation.

1.1.1. Research Concept and Design

To date, no study has explicitly looked at CPT. Therefore, to validate our hypothesis, the first part of this study considers the phenomenon of range anxiety to underpin the theoretical basis of our investigation, pointing to more significant trauma and its effect on new and existing EV drivers. We then examine the current EV sector by comparing sales volume, forecasts, and the lack of contemporary literature surrounding CPT extending beyond range anxiety. Rapid chargers were chosen as the research focus since they are the only charging option for long-range EV commuters on the UK motorway network, enabling a relatively quick full charge in under one hour. This timescale is accelerated if

(a) the car can accept higher charge rates and (b) if the rapid charger can deliver higher charge rates above the de-facto rapid charging standard of 50 kW per hour.

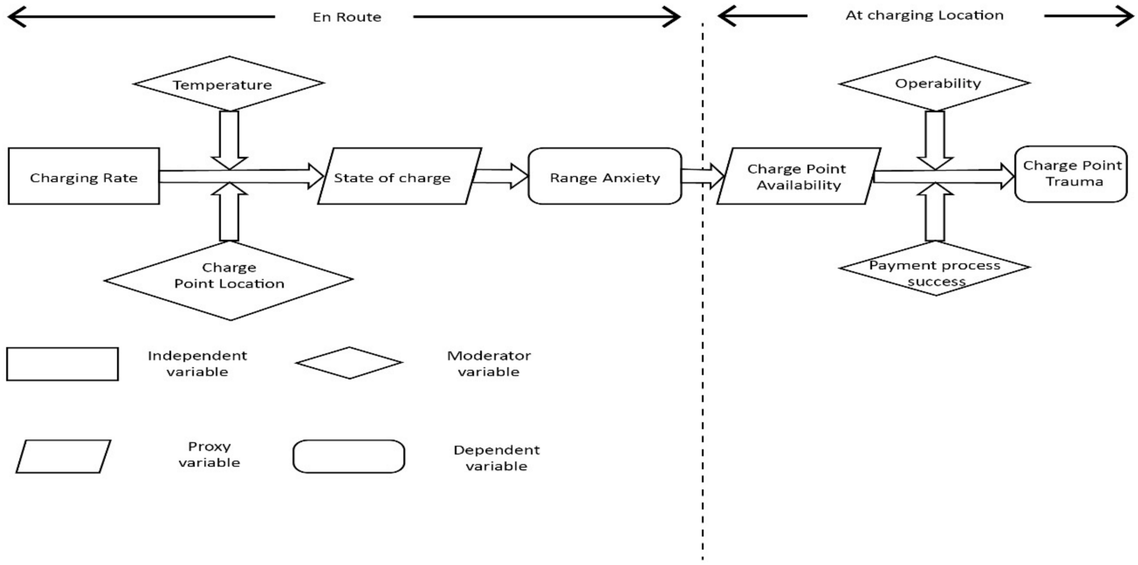

Figure 2. Theoretical framework showing the interrelationship between range anxiety and CPT.

1.1.2. Range Anxiety

EV drivers typically experience greater anxiety levels than traditional internal combustion engine ICE drivers due to a developing, relatively immature rapid charging network [8]. Advanced levels of range anxiety can potentially lead to adverse effects on an EV driver's reactions and may even cause unsafe driving behaviours. Because of this potential safety issue, several studies [8,9] have developed to comprehend range anxiety, including evaluation models and influential factors. Moreover, various solutions are proposed in the literature to mitigate range anxiety.

Rauh et al. [8] examined the assumption that range anxiety affects only inexperienced EV drivers and disappears as the driver gains more driving experience. However, our study suggests that even experienced EV drivers experience higher anxiety levels than experienced ICE drivers in similar situations. In Raugh's study [8], participants with diverse driving experiences are given a critical range situation, where the remaining EV range was lower than the journey length. By gauging range evaluation and range stress with different scales, investigators learnt that driving experience significantly affected all measured variables. With more experience, EV drivers tend to have less harmful range evaluation and hence range anxiety. Therefore, it is essential to increase the efficiency and effectiveness of the learning process for EV drivers. This study concurs with our field-based investigation in Section 3.

To enhance the factors that can relieve range anxiety, Franke et al. [9] designed a field study environment to examine several factors contributing to lower *everyday range stress* (ERS). The study revealed that variables such as consciously reducing instances of critical range situations, higher practical experience, emotional range competence, tolerance of low range, and experienced dependability of the EVs range calculation display were related to lower ERS. Furthermore, Franke confirmed that range anxiety is directly related to range and EV satisfaction.

We found few studies that check the influence of in-vehicle information systems (IVISs) on range anxiety. However, Eisel et al. [10] performed a battery EV field experiment under a live traffic state. The investigators noted the participant's psychometric range appraisal and psychophysiological feedback. They concluded that individuals perceived the critical range situation as less challenging and threatening with the provided charge rate calculating display. However, although the IVIS accuracy reduced the mean value of stress throughout the driving task, the investigators discovered that participants using IVIS's had higher levels of stress perception. These results indicate that often, range displays, however accurate, can increase depletion cognisance of range resources over time.

Many solutions are proposed in current literature to reduce EV drivers' range anxiety. Tannahill et al. [11] studied the future of range anxiety solutions by investigating a driver alerting algorithm proposed to minimise range anxiety. The critical advance of the algorithm is the progressive accuracy of EV range estimation. No complex computations are involved in the algorithm. Hence the algorithm can be applied on affordable microcontrollers and still achieve accurate results.

Faraj and Basir [12] suggested a path arrangement model based on battery capability and energy cost analysis. The study equates the battery capacity of the EV with the least energy cost of a round trip to the rapid charging station. If the battery capacity is lower than the distance to the charging station, the study advises the driver to recharge, avoiding being stranded. This model can also provide an accurate calculation of the available range to the EV driver. This model can moderate range anxiety, ultimately stimulating the growth of EVs.

Sarrafan et al. [13] proposed an algorithm that creates real-time recommendations in EV charging route planning. The algorithm is based on the collective calculation of a state of charge (SoC) estimation method and GPS, which can calculate and predict the EV's remaining range to the journey destination with the driver's data input. The function is realised through a real-time indicator system run by the algorithm. The EV user experience could effectively be improved by reduced range anxiety during the trip.

Tannahill et al. [14] suggested a new method of range calculation based on a state of charge (SoC) calculation method that was previously offered. This new approach accounts for a wide range of environmental, driver style, and behavioural factors. Thus, range estimation can be more precise than results drawn by established techniques, which simply consider vehicle efficiency and the SoC. This new range estimation method can notify the driver of the EV's range capability and propose recommendations on whether the EV needs to recharge before reaching the destination. However, our experience is that in the five years since this study, the range estimation methods in EVs have significantly improved, providing very accurate real-time range estimation.

This literature analysis is essential in verifying and advancing previous range anxiety investigations that we argue form a significant part of CPT's extended EV driver trauma phenomenon. Tannahill et al. [14] methodology was employed in route two, Section 3 of this study and produced almost identical results when analysed in Section 4. This experiment provided insight into individual differences in range stress when EV drivers are faced with a critical range situation for the first time, where participants were given a route of which the range was tailored close to the EVs range capacity. The results were helpful to formulate strategies aimed at reducing early EV experience range stress that may lead to lower CPT, as discussed in Section 4.

1.2. Study Concept and Design

For three months, we carried out seven controlled case studies that were split across two distinct routes, both using either motorways or A class trunk routes, described in Section 3. In each study, an EV driven by a novice driver set the benchmark for the successive ICE and EV drivers. In the benchmark trip, we employed a novice EV driver for both routes. Anxiety pinch points were recorded and used for key measurement milestones in each successive journey regardless of experience. Further detail on each anxiety milestone is contained in Appendix A.

During the seven benchmark studies, the driver's heart rate was recorded at critical points in the journey and transposed into anxiety levels using a simple matrix design detailed in Section 3. We retrospectively plotted the same anxiety pinch points for each trip made in an ICE vehicle, using the heart rate data assigned in real-time data paired with correlated anxiety calculations to provide a valid comparison with all case study

EV journeys. The critical anxiety pinch points are mapped in the two routes used in Figures 3 and 4.

Figure 3. Route 1. Southwest.

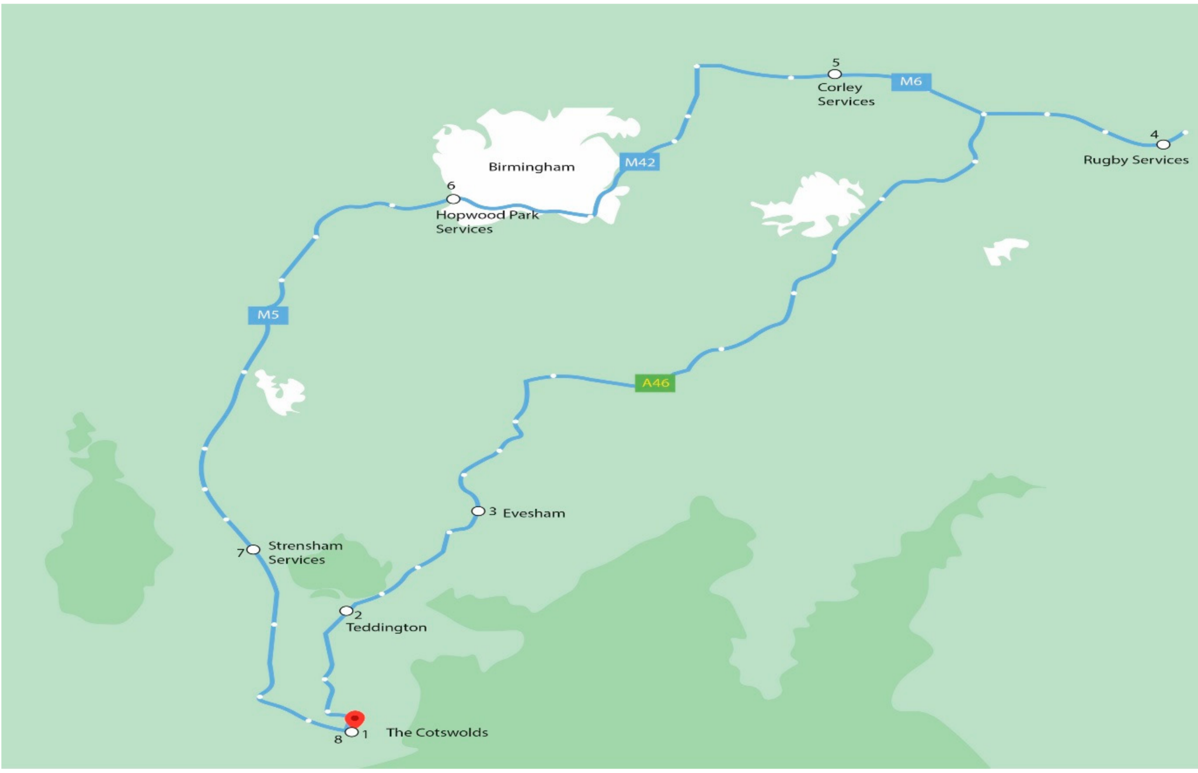

Figure 4. Route 2. North.

Section 4 discusses the study output and potential methods to mitigate CPT, one of the current barriers to EV adoption, leading into Section 5: where results and study limitations are presented. Finally, Section 6 summarises our conclusion suggesting future research opportunities.

1.3. Current EV Market

According to the Society of Motor Manufacturers and Traders (SMMT), the number of EVs on UK roads has increased from 2012 to 2020, as shown in Figure 5 [15]. Additionally, the study shows that from 1 January 2012 to 31 December 2020, 199,660 pure EVs were sold cumulatively in the UK market (excluding plug-in hybrids).

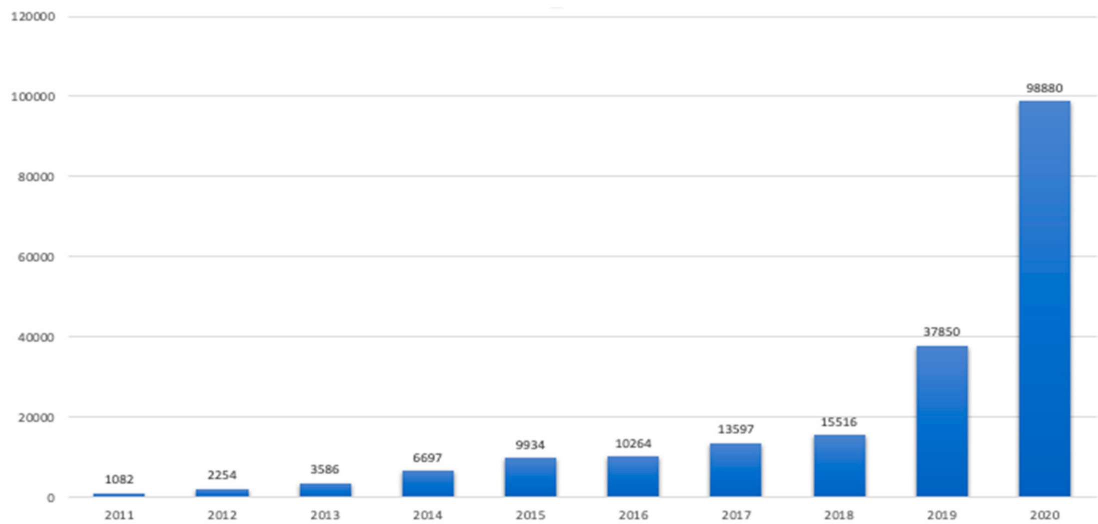

Figure 5. Growth in the number of EVs in the UK market 2011–2020 [15].

The increase in new EVs on UK roads directly affects availability and increased use of the UK rapid charging network, increasing additional driver anxiety compared with refuelling and commuting in traditional ICE vehicles. The logic behind this statement is that the average number of EV rapid charge points on UK Motorways ranges from 2 to 4 units, compared with 16 to 20 traditional fuel pumps in fossil fuel service stations.

The UK market share of pure EVs amounted to 5.8% of total new car sales [5], which is a significant milestone considering EVs current limited mass production. Traditional car companies have a limited portfolio of EVs compared to pure EV companies such as Tesla, who offers five EV models (2020). For example, Mercedes-Benz, BMW, and Audi have only two fully electric sport utility vehicles (SUVs), each in their current model ranges, while Jaguar has only one model. Further research reveals the SMMT and the International Energy Agency (IEA) [16] forecast that the demand for EVs will grow exponentially in line with the global transition to electric mobility [3,4]. The IEA also predicted that growth would be bolstered by increasing concerns regarding anthropogenic contamination of the environment, charging infrastructure deployment, policy changes, and EV affordability.

1.4. Purpose of This Investigation

The primary aim of this study is to determine whether CPT exists as a phenomenon among new and existing EV drivers and establish what factors stimulate this anxiety. Secondly, using our existing primary research, we aim to develop a possible link between weaknesses in the deployment and operation of the UK's current motorway rapid charging network strategy leading to CPT by embracing four main topics areas of research. The following four questions originate from our previous published survey's top four EV driver concerns [7] upon arrival at a charging station. Answers to these four questions will elucidate whether CPT is an emerging phenomenon.

1. Are there sufficient rapid chargers to meet current UK growth?
2. Are the operability service levels acceptable?
3. Are established rapid chargers live and available to use?
4. Is there an operational issue with payment processing?

Finally, the study will determine if the cumulative effect of any weaknesses in these areas reveal a cause-and-effect relationship that may negatively impact the future growth of the UK EV market through analysis of the data from our seven case studies by employing a correlated *T*-Test analysis.

After evaluating, considering, and discussing our primary research through surveys and case studies, we then set out a proposal for future analysis with recommendations for further investigation. The objective is to minimise barriers to EV growth connected to *CPT*, thus setting a path of equivalence with 'always available' traditional fossil fuel service stations by exploiting a proposed technological and regulatory solution.

1.5. The Existing Reality of EV Rapid Charging

Although a body of research has discussed EV user experiences in general terms [2,15,17], less attention is paid to charting EV user involvement and CPT for typical long-distance travel that relies entirely on the motorway rapid charger network. Figure 2 illustrates a representative long-distance EV commute using a mid-range 60 kWh battery to travel a maximum 500-mile notional route comparable with our case studies one, two, three, and four.

One of the chief differences between traditional fossil fuel and EV commuting is that, generally, ICE vehicles have a greater range per refuel than EVs. Furthermore, there are three additional differentiators for EV users that traditional ICE drivers would not experience. We argue that these three factors (points 1, 2, and 3 in Figure 6) are the prime source of a psycho-technical and behavioural phenomenon amongst EV drivers that we notionally designate as CPT.

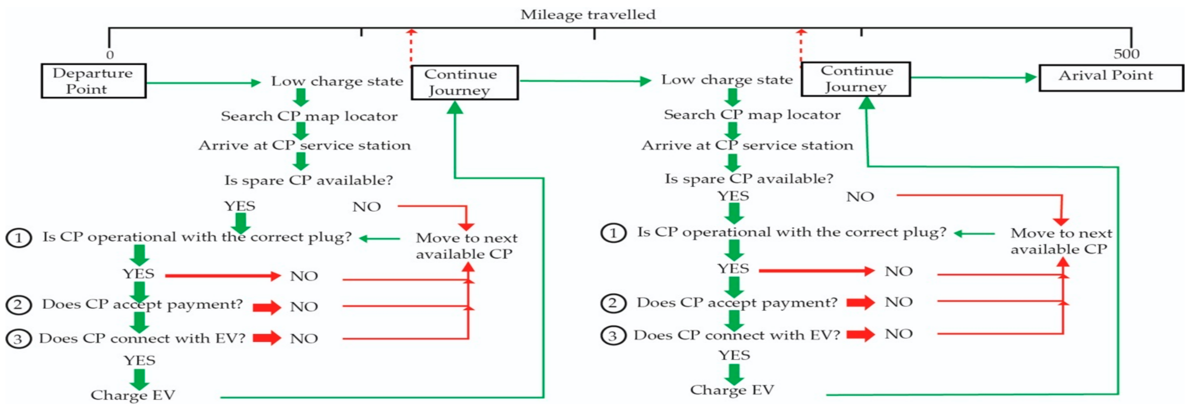

Figure 6. EV user long distance commute—flow chart highlighting three main user issues.

This study is the first to focus on the four significant causes of CPT. These causes have been identified through our peer reviewed EV user survey in Q4 of 2019 [7] and our recent case studies investigation from Q2 2021. The top four issues concerning most new and existing EV users are:

1. Lack of sufficient rapid chargers in key commuting locations.
2. Charge point operating correctly with correct connector available for the EV.
3. Charge point payment process (i.e., contactless pay as you go or subscription model only)
4. Charge point connection. Does the charge point communicate with the EV correctly, successfully delivering the required charge?

These issues are unfamiliar to a traditional ICE driver. Our research [7] emphasises four main concerns that face every EV driver visiting a public rapid charge station that proliferates the phenomenon of CPT backed by our data analysis in Section 4. Furthermore, despite a decade of research on the technological aspects of EVs and their user effects, existing research has primarily focused on the declining phenomenon of range anxiety in a similar context. Furthermore, Pevec et al. [18] agree that increasing EV battery capacity has made range anxiety much less of an issue for day-to-day driving. Current EVs are increasingly built with larger capacity batteries offering far greater mile range per charge.

1.6. Supporting Statistics

The distribution of the rapid charging station is another potential cause for CPT since long-range EV drivers must align their journey with the rapid charger network. Deviation from the route could result in inconveniences and increased mileage for customers. Additional concern surrounds some rapid charging stations with exclusivity to individual EV brands, leaving owners of other EV brands unable to access these rapid charger networks. Furthermore, although the number of public charge stations has increased tenfold from a low of 3672 in 2015 to 21,989 in December 2020 (Figure 7), *CPT* is expected to continue since the growth of rapid charge points has not developed in tandem with the demand for EVs [19].

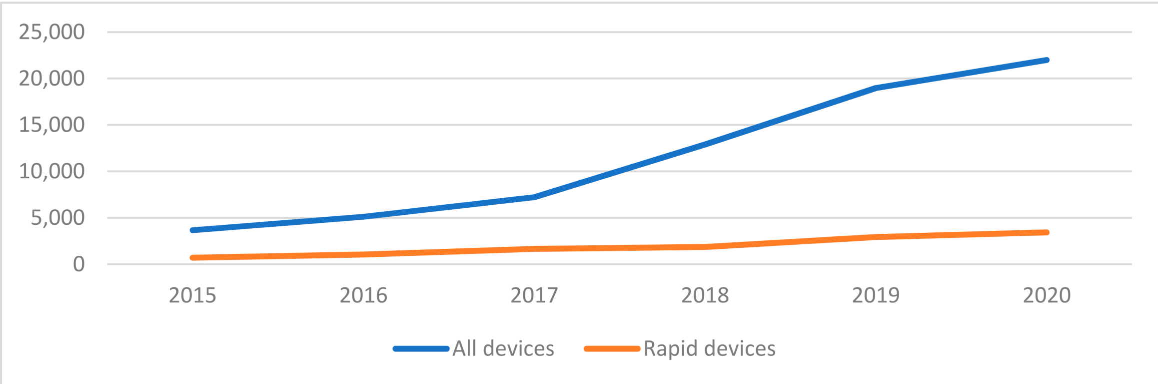

Figure 7. Growth in public charging station network across the UK [19].

1.7. EV Rapid Charging Review

The service availability of rapid charging stations is critical considering the limited mile range of available EVs [20,21]. Although Tesla has a significant network of supercharger points for EVs across UK trunk routes [22], we have not included them in our study because they are exclusive to Tesla drivers. Further, observations drawn from Tesla's website regarding the distribution of charging infrastructure is consistent with an investigation of EV and infrastructure in the UK by Hirst [1]. We concur, arguing that public charge points are still unevenly distributed across the UK, implicating that access to charge points is still something of a postcode lottery.

Bunce et al. [2] report survey results of EV drivers in the UK, establishing that EV driver anxiety was most pronounced in new owners. Our survey of commuting rapid charge EV users on main motorway routes confirms this finding. After a three-month follow-up, the drivers had a more positive perception of recharging. However, no driver equated their experience to traditional petrol/diesel vehicle refuelling [2], which is a critical area linked to our CPT research in Section 3. We contend this has been overlooked in past studies that investigate EV driver anxiety.

The positive attitudes towards EVs among the surveyed drivers in the group were paradoxical, considering they did not rely solely on public charging infrastructure, instead opting to charge their EVs overnight at home when feasible. According to Bunce et al. [2], UK EV drivers maintained that public charging infrastructure for EVs was unnecessary, with 83.7% of the surveyed drivers opting to charge their EVs in private residences. However, only 20% of these respondents were long-distance commuters. We argue the preference for overnight charging at home can be partly explained by the inadequacy of the EV public charging infrastructure in the UK, as shown in Figure 8 [19]. Furthermore, we contend that as EVs become mainstream, there will be a growing number of potential EV users living in terraced houses and apartments with no access to or ability to install an overnight home charger, making the availability of rapid or superchargers essential for this UK demographic.

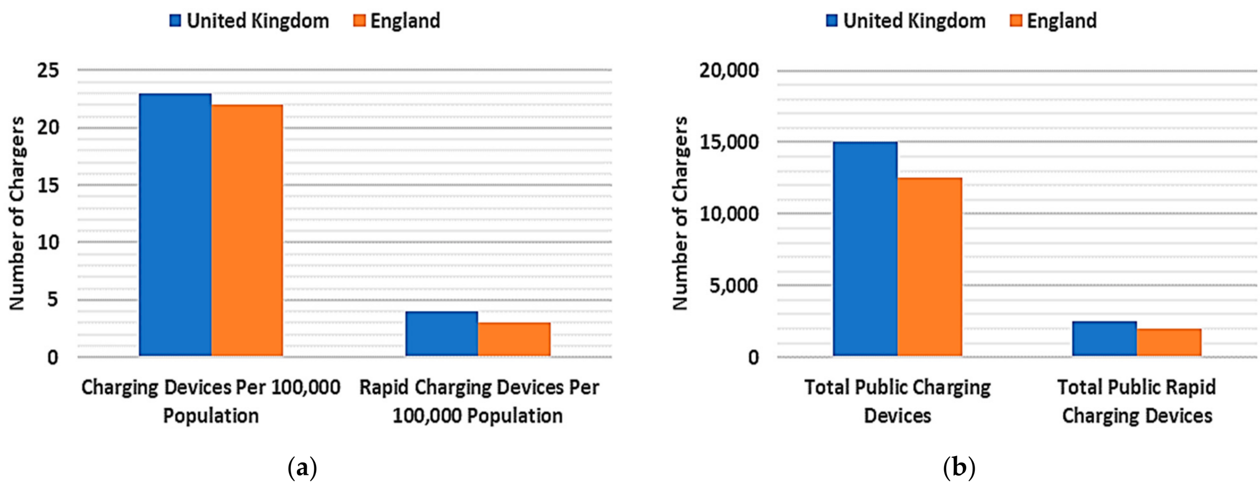

Figure 8. (**a**) EV Charge Point statistics 2019 [19]. (**b**) EV Charge Points per capita percentage 2019 [19].

Moreover, we agree with Delbosc et al. [23], noting that early adopters were likely to be more affluent and own stand-alone homes with drives or garages for practical installation of individual charging points, rather than urban dwellers who may rely on public street charging facilities. The UK pattern contrasts significantly with the charging behaviours of US and Chinese EV consumers who, according to M. Nicholas et al. [24], rely more heavily on public charging infrastructure due to the greater distances between towns. This reveals that fundamental technological constraints apply to both urban and long-haul inter-city commuters alike [25].

1.8. EV Energy Storage Technologies Driving CPT; Current R&D Challenges

From an engineering perspective, the progress made in battery energy storage systems predicts EV efficiency in terms of mileage and charging requirements. This claim is supported by a comparative analysis of EV batteries, mileage range, charge times, energy costs, and Wh/km [26]. Based on the information from this research, there is a direct relationship among the standard charging time, range, Wh/km, and battery chemistry. Higher capacity batteries generally require longer charge times that superchargers may be able to address. The downside of larger battery packs is the weight of the lithium-ion batteries, which we believe contradicts previous claims by Tarascon and Armand [26], who argued that lithium-ion batteries offered a lightweight design, when in fact, most EVs comparable in size to equivalent ICE vehicles weigh between 30% to 50% more [27].

Energy storage faces multiple technological barriers, including EV energy requirements, since higher energy translates to higher battery costs and extra weight. However, even if these cost and weight factors are addressed, lithium-ion capacity depletion remains a problem for EVs [27] linked to the degradation of electrode materials, accumulation of substrates, higher depth of discharge and thermal-induced damage [28].

The challenges linked to power and energy fading and the degradation in lithium-ion batteries have attracted considerable research attention towards developing novel supercapacitor electrode materials from diverse resources. Examples include carbon nanomaterials [29], graphene [30,31], boron, and titanium [32,33], among others. However, achieving both high power and high energy density has remained a challenge. The inherent limitations of supercapacitors have left lithium-ion batteries the preferred energy storage systems for EVs [34]. The main question is whether combining these two energy storage technologies could facilitate exploiting the synergistic benefits afforded by both [35]. Based on the current state of research regarding development of charging infrastructure, it can be argued that technological limitations for energy storage devices have had a domino effect on the uptake of EVs in the UK market. This view is consistent with market research by McKinsey consultants [36] who explain how EV battery energy storage was one of the two major problems facing EV owners and potential consumers, contributing to range anxiety.

However, the theoretical arguments made in the study concerning the adverse impact of energy storage technologies on the sale of EVs can be discounted, considering that cost was also a critical impediment to the availability of EVs. The list prices for most new EVs are incomparable to standard fossil fuel-powered vehicles if you compare them with similar ICE rivals that generally still boast a more significant range per refill.

1.9. Cost and Purchase of EV and Charging Infrastructure in the UK

The cost of EV technologies and CPT has indirectly contributed to the limited purchase of EVs in the UK [37]. The capital expense of EV technologies encompasses the cost of installing a nationwide public charging infrastructure for EVs in addition to the purchase cost of EVs. According to the US Department of Energy [38], like the UK, charge point systems are grouped into three areas: level 1, level 2, and DC rapid charge based on the power requirements and cost. The power requirements and cost estimates for charging infrastructure are balanced through grid planning and user needs [37]. The data presented in Figure 8a,b shows the secondary requirements and power demands for different levels of charging infrastructure contributing to CPT. Rapid charging equipment is expensive and requires additional modifications to the local electricity grid. In many cases, rapid charge stations are located far from main trunk routes to satisfy grid availability rather than EV user's preference and convenience [39]. Conversely, the more affordable Level 1 and 2 charging infrastructure provides a far slower rate of charge leading to limited range versus charge time but is generally far less expensive to install and with no location constraints due to the low power requirements.

Considering the link between range and charging infrastructure, DC rapid and supercharging infrastructure installation is necessary. This observation is consistent with a report from the UK House of Commons [1] recommending an increase in charge stations. However, it is paradoxical to note that most current deployed charge infrastructure is categorised as a Level 2 standard charge, as shown in Figure 9 [40]. The installation of typical charging infrastructure provides limited reprieve for EV owners considering that EVs with longer mile ranges have higher energy requirements. Beyond this, other concerns include the pace of deploying charging infrastructure. Based on the data collated by Statista [40], the number of regular charge stations had increased from 1500 to 20,451, which translates to about 19,000 new charge stations over eight years. If these growth trends are sustained, there will be a critical shortage of charging infrastructure in the UK by 2030 [1].

According to a 2019 government report [19], the number of charging stations should increase in line with the ratios presented in Figure 9. However, it is essential to note that these estimates are grounded on the assumption of constant projected growth in EV sales. There is no certainty that this projected growth is sustainable from an abstract perspective, considering that the EV market's development depends on multiple confounding variables. Moreover, it is difficult to accurately predict the number of private charge stations required for residential homes or offices.

Beyond the concerns illustrated in Figure 9, CPT is exacerbated because current EV models do not have standard power requirements [7]. Additionally, EVs require different connectors to charge in the public charging infrastructure, as highlighted in Figure 10. The lack of universally compatible infrastructure limits the utility of available charging infrastructure. As noted in the preceding sections, the current charging infrastructure is often dedicated to a specific brand. For example, non-Tesla vehicles cannot participate in the Tesla supercharging network. The incompatibility of charge devices and infrastructure is the third leading contributor to CPT [7]. For instance, GB/T is a Chinese-based consortium standard, not yet released or used in the UK, but employed extensively across the Far East and may be introduced globally. To further investigate the extent that CPT may have impeded EV growth in the UK thus far, it is essential to test our hypothesis using our case studies and our peer-reviewed surveys in Section 3.

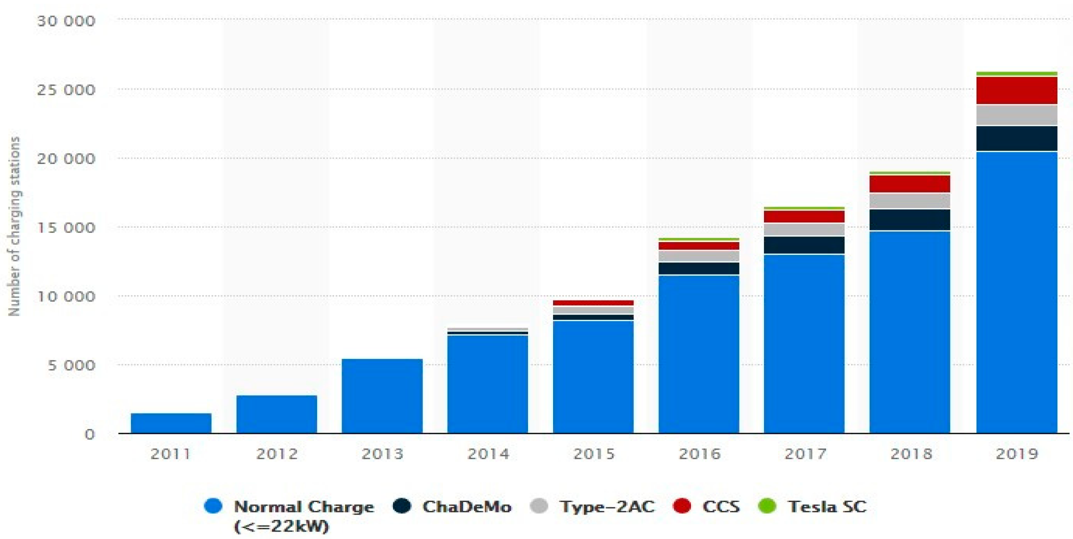

Figure 9. Growth in UK charge points by connection type [40].

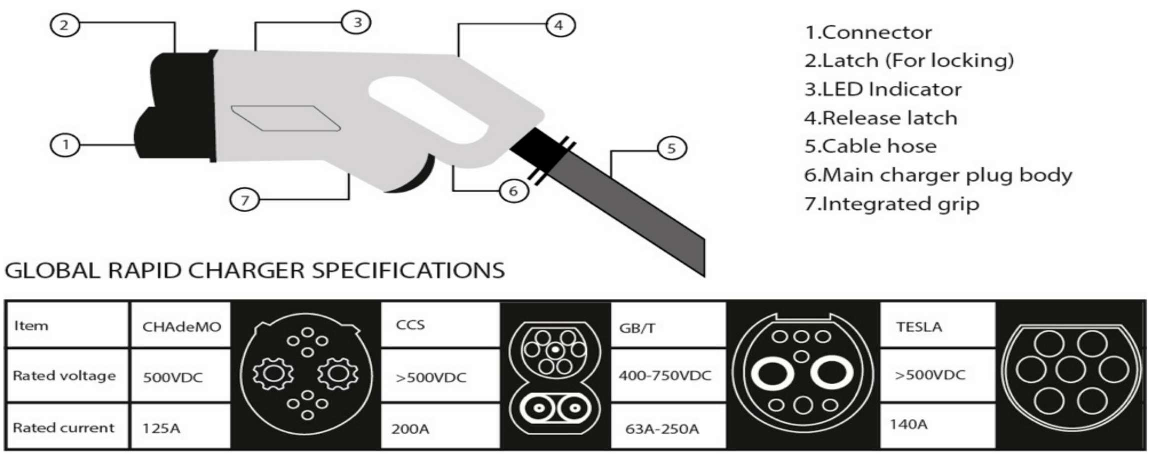

Figure 10. Disparate rapid charge connector standards in UK (excepting GB/T).

2. Research Methodology and Analysis

2.1. Setting

The research setting is the UK EV sector (i.e., England, Scotland, Wales, and Northern Ireland). However, some comparisons are made with Norway [41], USA [42], and China [43] in the secondary data set to establish benchmarks and compare countries because they have made significant technological progress in EVs and supporting infrastructure that could address CPT in the UK. All three countries benefited from generous stimuli and incentives, more so than the typical low-level incentives and grants offered in the UK. The Norwegian EV market is the most developed in the world per capita [41]. It has conversely attracted the highest-level government subsidies in the form of EV grants of up to fifty per cent of the purchase price. Additionally, Norway's state-sponsored charging network incentives are typically 100% of installation and material costs [41].

Research has reported that government subsidies toward car purchases vary from state to state in the USA, with up to USD 7500 offered on all new EV sales and up to 100% government or federal grants toward charging infrastructure installation and material costs [42]. Similar car subsidies currently exist in China, averaging USD 2500 per EV whilst charging infrastructure is typically fully subsidised for material and installation costs [43]. By contrast, UK EV grants are only available for cars sold under GBP 40,000, and that subsidy currently equates to only GBP 2500. Furthermore, UK subsidies for charging infrastructure and material costs are generally awarded via a bidding process. As a result, they typically amount to 70% of total costs, although this does not apply to all charge point deployment [44].

2.2. Data Analysis

The data obtained from this study were analysed using the investigator's primary quantitative data, coded from a mixed-method study, to provide a balanced result. This is an ideal method for exploring qualitative and quantitative information [45,46], even though there are some minor concerns regarding the trustworthiness of this approach. Additionally, data obtained from the House of Commons report [1], SMMT [40], Deloitte [47], and other stakeholders were evaluated. However, we found that older datasets (i.e., before 2015) were unusable due to obsolete data presented in each report, making them unrepresentative of the current dynamic growth in the EV environment.

3. Case Study Introduction, Survey Outcome and Methodology

To validate our hypothesis in Section 1, it was necessary to underpin the investigation by generating valid data using a robust method of measuring the anxiety levels experienced by two archetypal EV drivers [48]—one experienced in EV driving for more than a year and one completely inexperienced in EV driving. We illustrate the complete trip and driver profile in Section 1.3, Table 1. We first benchmarked each investigation using two separate routes shown in Figures 3 and 4 by employing a novice EV driver. This methodology created a map of novice EV driver situational anxiety markers, and these pinch points were subsequently used for anxiety measurements in each successive case study. Full details of why these points resulted in high anxiety levels are detailed in Appendix A. There were more marker points on the outward journeys due to several forced stops to recharge, due to either faulty chargers, inability to pay by card or charge point closed, detailed in Appendix A. On the return journeys, each driver learned which charging stations were operative with a card payment facility, thus negating the same number of stops and subsequently raised anxiety levels.

Table 1. Driver profiles across both routes in Section 3 case studies.

		Route 1—Southwest				Route 2—North		
	Driver Profile	**CS1**	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**
Driver 1	Experienced ICE driver was employed in study one and five. This driver had more than ten-year's experience with a variety of ICE vehicles and long-distance driving knowledge.							
Driver 2	Novice EV driver used in study two and six. This driver was an experienced ICE driver with long distance driving knowledge, but this was the driver's first experience in an EV.		**B**				**B**	
Driver 3	A different novice EV driver was used in study 3. This driver was an experienced ICE driver with long distance driving knowledge, but this was the drivers first experience in an EV.							
Driver 4	One experienced EV driver was used for studies four and seven. This driver was an experienced ICE driver in long distance driving, with more than two years driving experience in an EV.							
Key	**CS** **Case study**		**B**		**Benchmark study**			

At the start point, finish point, and each intermediate stop, the driver's heart rate was monitored by an Apple smartwatch worn by each driver throughout every trip. The watch measured real-time BPM heart rate beats per minute (BPM) and stored on a cloud-based server, updated each minute. We chose the FDA approved heart rate monitor Apple Series 4 smartwatch with an integrated heart monitor app. The Apple Watch Series 4 employs two light sensors to track the user's heart rate using photoplethysmography (PPG) in blood in peripheral circulation [49]. PPG is deemed medical grade and accurately measures heart rate in normal sinus rhythm with a 96% efficacy rate by employing a simple optical process that detects changes in volumetric variations or pulses in blood [50]. Although not a clinical precision instrument, it was deemed appropriate for each of the five case studies. Furthermore, the literature has recently confirmed Apple Watch accuracy [51], supporting its efficacy for consumer use.

The effectiveness of using heart rate measurements as an indicator to monitor anxiety has been recognised in a recent paper by Khanade and Sasangohar [52]. This is considered a vital method to observe the state of anxiety, PTSD, and other related disorders. Thus, key journey points in each case study (one to four) were ranked by anxiety levels using the measured driver's heart rate for each significant journey point using data from the driver's smartwatch heart rate monitor. Case studies five to seven further reinforced our investigation by conducting an alternative route for ICE and EV journeys compared with stage one case studies. As a benchmark, we measured each driver's resting heart rate the previous day. Both were within the same age range stating that the maximum healthy BPM should be 160 BPM [53]. In the first three case studies, driver one's resting BPM rate measured 65, and driver two's resting rate measured 61. In case studies four and five, the driver's resting heart rate measured 63 BPM.

We then converted the heart rate data into anxiety levels ranked from 1 to 10, with resting heart rate ranked as 1 in the range of 60–65 BPM up to and including rank 10, which represented 160 BPM or above (Table 2). All rest stops consisted of either water or decaffeinated tea or coffee to prevent caffeine from artificially increasing the heart rate of both drivers. In addition to caffeine [54], in new research by Chapman et al. [45], it was found that sugar or fructose-sweetened drinks can similarly affect heart rate and blood pressure. Hence, the drivers consumed only sugar-free beverages, caffeine-free drinks, or sugar-free snacks during the investigation.

Table 2. Heart rate levels correlated to anxiety level ranking for data analysis. Level 1 is considered negligible, while level 10 is considered extremely high.

Heart rate	60–65	66–74	75–84	85–94	95–104	105–114	115–124	125–134	135–144	145–160
Anxiety level	1	2	3	4	5	6	7	8	9	10

CASE STUDY 1. Route 1.
Round trip from the Cotswolds to Cornwall and back—UK
Vehicle: 2-L diesel compact SUV ICE
Experienced ICE driver
Round trip 430 miles.
Payment method: Apple Pay via iPhone 12 Pro Max
Time to destination: 3 h 42 min. Average speed 58 mph.
Return trip back to the start point: 3 h 55 min. Average speed 55.2 mph.
Date: 17 April 2021.

The first case study plotted a direct round trip. It is replicated in case study two to four to compare the 430-mile journey using a modern diesel-powered ICE SUV with an EV. The ICE vehicle used in case study one and five has an official maximum range of 480 miles per full tank. Despite the ability to complete this round trip without refuelling, the convenience of driving the ICE test vehicle is that it is possible to use almost any service station to refuel. Additionally, drivers can make a simple payment transaction with a contactless smartphone at the pump or payment kiosk.

The researchers used two iPhone® 12 Pro Max smartphones with fully functioning Apple Pay contactless apps set up for these studies. The motive for adopting this payment method is that it is widely accepted at most retail outlets, with more than a quarter of a million UK stores and service stations receiving this form of payment. All drivers were bound by UK, COVID 19 pandemic cashless payment rules and guidelines during this investigation. Additionally, most retail premises took only contactless payments at the time of this investigation, accepting either contactless credit and debit cards, Apple Pay, Samsung Pay, or Google Pay. Neither driver nor passenger took cash or card with them for case study one, two or three. The driver's heart rate was monitored and uploaded live to an Apple cloud-based server throughout the journey. Correlating anxiety levels were retrospectively accessed to match all key points driven by the EV trips' events.

The researchers acquired a 2-L diesel medium-sized SUV for case studies one and five. This is a typical long-distance family class vehicle, with a World Harmonised Light Vehicle Test Procedure (WLTP) of 45 mpg consumption, equating to 480 miles on a full fuel tank.

The plotted route was predominantly based on motorways and dual carriageways using ZapMap® EV rapid charging data [55]. The route was entered into the in-car satellite navigation from point A in the Cotswolds to point B in Cornwall UK—215 miles. The investigators were confident that the ICE 2 Litre SUV would make the round trip on a single tank of fuel. However, to mitigate any refuelling or payment problems along the route, the drivers erred on the side of caution, deciding that it would be prudent to fill up mid-way on the return leg of the journey to cover any unforeseen en route complications.

The researchers departed the Cotswolds at 07:00 on Saturday, 17 April 2021. The ambient temperature was 12 °C. Two adults were travelling without luggage. The critical points of the journey were recorded using the driver's heart rate data, and corresponding anxiety levels were entered in the table below in Table 3.

Table 3. Case study 1. Journey anxiety levels based on heart rate for ICE SUV.

Key Points on the Journey		Driver 1 Outbound		Driver 2 Inbound	
		Heart Rate	Anxiety Level	Heart Rate	Anxiety Level
1.	Departure—Cotswolds	61	1		
2.	M5 J.11	72	2		
3.	Taunton Deane Services	66	2		
4.	Arrival and return—Cornwall	66	2	71	2
5.	Taunton Deane Services			73	2
6.	Arrival—Cotswolds			63	1

CASE STUDY 2. Route 1.
Round trip from the Cotswolds to Cornwall and back—UK
Vehicle: VW iD3 pure electric hatchback
Novice EV Driver
Round trip 430 miles.
Payment method: Apple Pay via iPhone 12 Pro Max
Time to destination: 4 hrs 49 min. Average speed: 45 mph (including stops).
Return trip back to the start point: 3 hrs 57 min. Average speed of 54 mph.
Date: 24 April 2021.

The second case study determined whether it was possible to travel a round trip of 430 miles in a modern EV in the same manner and with the same ease as driving conventional petrol or diesel cars (case study one). Again, two iPhone 12 Pro Max smartphones were used for payment on this trip, with fully functioning Apple Pay contactless apps already set up and established for regular use in the UK. Rapid charging locations were selected based on each location's claim that contactless payment is available in *guest mode*. Neither driver nor passenger took cash or card with them for this study. A VW iD3 was acquired for this case study since it is a new EV model in the small hatchback family class, and the WLTP range is stated at 264 miles on a full charge.

The drivers plotted an identical route to case study one. The route was predominantly motorway and dual carriageway based on ZapMap® EV rapid charging data [55] and entered with a start and finish coordinate using the in-car satellite navigation system from point A in the Cotswolds to point B in Cornwall, a total distance of 215 miles. The investigators were reasonably confident that the VW iD3 would narrowly reach the destination point on a single charge if charging or payment problems were encountered along the route. However, it was still deemed prudent to top-up at the halfway point to cover any unforeseen eventualities that may lie ahead.

The researchers departed the Cotswolds at 16:00 on Saturday, 24 April 2021. The ambient temperature was 15 °C. Two adults were travelling, plus two overnight suitcases. The departure point was just 9 miles from the M5. Critical points of the whole journey were recorded with the driver's heart rates and corresponding anxiety levels entered in the table, highlighted in Table 4.

Table 4. Case study 2. Journey anxiety levels based on heart rate—EV full electric.

Key Points on the Journey		Driver 1 Outbound		Driver 2 Inbound	
		Heart Rate	Anxiety Level	Heart Rate	Anxiety Level
1.	Departure—Cotswolds	76	3		
2.	M5 J.11	87	4		
3.	Cullompton Services	89	4		
4.	A30 garden centre	107	6		
5.	Supermarket charger	110	6		
6.	Cornwall Services	107	6		
7.	Destination—Cornwall	88	4		
8.	Departure back			85	4
9.	Cullompton services			88	4
10.	Arrival—Cotswolds			71	2

CASE STUDY 3. Route 1.
Round trip from the Cotswolds to Cornwall and back—UK
Vehicle: VW iD3 pure electric hatchback
Novice EV Driver
Round trip 430 miles.
Payment method: Apple Pay via iPhone 12 Pro Max and two contactless credit cards
Time to destination: 4 h 32 min. Average speed: 48 mph (including stops).
Return trip back to the start point: 3 h 57 min. Average speed: 54 mph.
Date: 1 May 2021.

The third case study replicates study two with the addition of access to Apple Pay or contactless credit cards. The researchers anticipated that this trip would produce far lower anxiety levels than study two and produce results comparable to study one. Again, two iPhone 12 Pro Max smartphones were used for payment on this trip, with fully functioning Apple Pay contactless apps already set up, and two contactless credit cards were made available for locations where Apple Pay was not acceptable. Rapid charging locations were selected based on each location's claim that contactless payment is available in *guest mode*.

Again, a VW iD3 was used for this case study. The drivers plotted an identical route to case study one and two. The investigators were reasonably confident that the VW iD3 would reach the destination point on a single charge if charging or payment problems were encountered along the route. Although, the drivers planned to top-up at the halfway point to cover any unforeseen eventualities that may lie ahead.

The researchers departed the Cotswolds at 15:30 on Saturday, 1 May 2021. The ambient temperature was 17 °C. Two adults were travelling, plus two overnight cases. The departure point was just 9 miles from the M5. The critical points of the whole journey were recorded with the driver's heart rates and corresponding anxiety levels entered in the table, highlighted in Table 5.

Table 5. Case study 3. Anxiety levels based on heart rate—EV (cards and Apple Pay).

Key Points on the Journey		Driver 1 Outbound		Driver 2 Inbound	
		Heart Rate	Anxiety Level	Heart Rate	Anxiety Level
1.	Departure—Cotswold's	65	1		
2.	M5 J.11	77	3		
3.	Cullompton Services	89	4		
4.	A30 garden centre	78	3		
5.	Supermarket charger	81	3		
6.	Cornwall Services	84	3		
7.	Destination—Cornwall	76	3		
8.	Departure back			78	3
9.	Cullompton services			83	3
10.	Arrival—Cotswolds			71	2

CASE STUDY 4. Route 1
Round trip from the Cotswolds to Cornwall and back—UK
Vehicle: VW iD3 pure electric hatchback
Experienced EV Driver
Round trip 430 miles.
Payment method: Apple Pay via iPhone 12 Pro Max and two contactless credit cards
Time to destination: 4 h 32 min. Average speed: 48 mph (including stops).
Return trip back to the start point: 3 h 57 min. Average speed: 54 mph.
Date: 1 May 2021.

The fourth case study replicates study two, with access to Apple Pay® contactless payment app. The researchers anticipated that this trip would produce far lower anxiety levels than study two and three, producing results comparable to study one due to the relatively long EV experience of the driver. Again, two iPhone 12 Pro Max smartphones were used for payment on this trip, with fully functioning Apple Pay contactless apps already set up. Rapid charging locations were selected based on each location's claim that contactless payment is available in *guest mode*.

Again, a VW iD3 was used for this case study. The drivers plotted an identical route to case study one, two, and three. The investigators were reasonably confident that the VW iD3 would reach the destination point on a single charge if charging or payment problems were encountered along the route. Although, the driver planned to top-up at the halfway point to cover any unforeseen eventualities that may lie ahead.

The driver and observer departed the Cotswolds at 15:30 on Saturday, 1 May 2021. The ambient temperature was 17 °C. Two adults were travelling, plus two overnight cases. The departure point was just 9 miles from the M5. The critical points of the whole journey were recorded with the driver's heart rates and corresponding anxiety levels entered in the table, highlighted in Table 6.

Table 6. Case study 4. Anxiety levels based on heart rate—EV (cards and Apple Pay).

Key Points on the Journey		Driver 1 Outbound		Driver 1 Inbound	
		Heart Rate	Anxiety Level	Heart Rate	Anxiety Level
1.	Departure—Cotswold's	68	2		
2.	M5 J.11	77	3		
3.	Cullompton Services	73	3		
4.	A30 garden centre	85	4		
5.	Supermarket charger	78	3		
6.	Cornwall Services	84	3		
7.	Destination—Cornwall	76	3		
8.	Departure back			78	3
9.	Cullompton services			83	2
10.	Arrival—Cotswolds			71	1

By overlaying all four case studies in a linear representation Figure 11 (1, 2, 3, and 4), the driver anxiety levels reveal the true extent to which EV charging experiences affect driver anxiety levels compared to the same journey in a traditional ICE vehicle. The extreme EV driver anxiety levels were recorded in case study two. Equipped with only a contactless payment app on a mobile phone, drivers anxiety levels proved to rise to higher levels than study one and three due to rapid charger access and payment issues. We discuss the reasons for differing anxiety levels in Section 4.

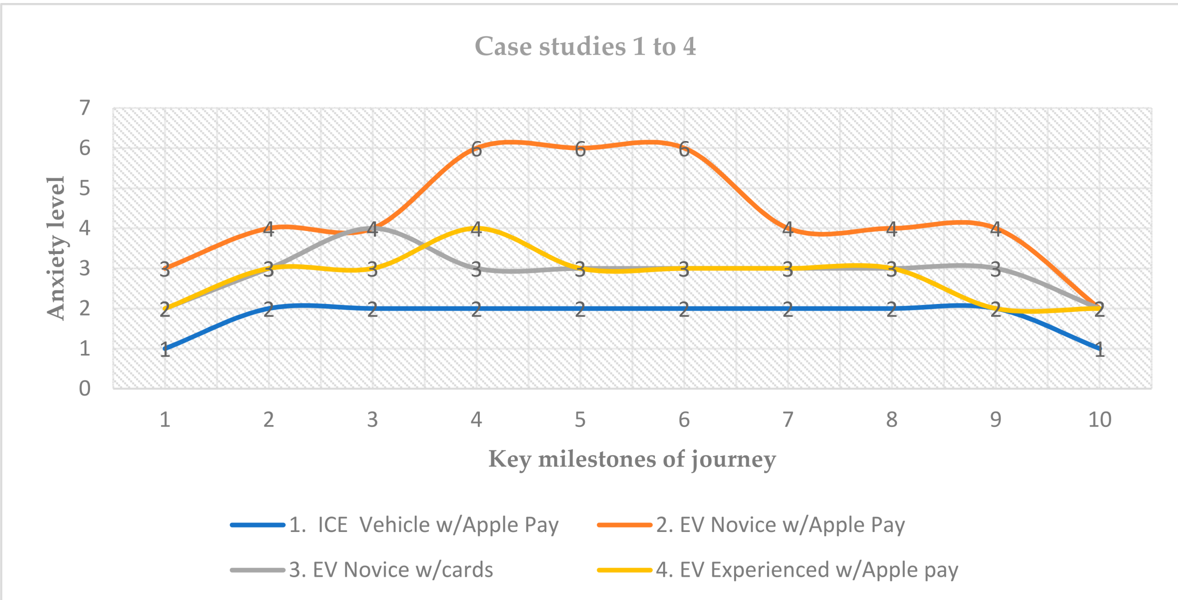

Figure 11. Case studies 1, 2, 3, and 4. Anxiety level data across all journey points.

The investigators then planned a route north of the Cotswolds spanning a main A-Class trunk route and three different motorways. The mid-way recharging and refreshment point was a new service station on the M6, hosting traditional refuelling facilities and the UK's latest cluster of eight 'available to all' 350 kW ultra-rapid chargers, plus eight dedicated Tesla superchargers.

CASE STUDY 5. Route 2
Round trip from the Cotswolds to Rugby and back, via Birmingham—UK.
Vehicle: 2-L diesel compact SUV ICE
Experienced ICE Driver
Total distance: 156 miles.
Payment method: Payment method: Apple Pay via iPhone 12 Pro Max
Vehicle range on departure 92 miles
Round trip back to the start point: 2 h 56 min. Average speed of 53.8 mph.
Date: Friday, 14 May 2021.

The fifth case study employs an independent driver and one passenger with the role of researcher-observer. The car in this case study is identical to case study one, a 2-litre diesel compact SUV ICE. The driver was trained in the diesel SUV operation and basic working theory, including familiarity with all controls. Additionally, the driver was fully insured for the research journey before the commencement of the investigation. This study aims to benchmark the route for an ICE vehicle, including the driver's anxiety level, before carrying out an identical journey in an EV (case study 6). One researcher travelled as a rear seat passenger and monitored the driver's behaviours associated with using conventional petrol or diesel cars. The driver's only form of payment was a contactless Apple smartphone using Apple Pay®. The driver was provided with ZapMap [55] to plot a break in the journey mid-point for refreshments and fuel top-up and wore an Apple Watch 4 to monitor and measure heartbeat at critical points along the route. These data were then used to measure and correlate anxiety levels throughout the journey.

The driver plotted a new route for a round trip, starting and finishing at the Cotswold start point. The route was predominantly motorway, dual carriageway and A-class trunk roads based on ZapMap® EV rapid charging data [55]. The driver entered the start, interim, and finish coordinates using the in-car satellite navigation system from the Cotswolds to Rugby, then past Birmingham and finally returning to the start point in the Cotswolds. The total journey distance was 156 miles. However, the investigators deliberately provided the car to the driver with just a 92-mile range, compelling the driver to refill with diesel at the mid-way point.

The driver and observer departed the Cotswolds at 13:00 h on Friday, 14 May 2021. The ambient temperature was 17 °C. Two adults were travelling, comprising one researcher as an observer and one as a driver. The critical journey points were recorded with corresponding driver heart rates and resultant anxiety levels entered in the table, highlighted in Table 7.

Table 7. Case study 5. Anxiety levels based on heart rate—ICE SUV (Apple Pay only).

Case Study 5		Driver Round Trip	
	Key Points on the Journey	**Heart Rate**	**Anxiety Level**
1.	Departure—Cotswolds	68	2
2.	Teddington Hands Roundabout—A46—no stop	74	2
3.	Morrisons supermarket—Evesham A46—optional charge point	72	2
4.	Rugby Services—M6 mid-way—charge and refreshment break	70	3
5.	Corley Services—M6—no stop	67	2
6.	Hopwood Park Services—M42—no stop	69	2
7.	Strensham Services—M5—no stop	73	2
8.	Arrival—Cotswolds	72	2

CASE STUDY 6. Route 2.
Round trip from the Cotswolds to Rugby and back via Birmingham—UK.
Vehicle: VW iD3 pure electric hatchback
Novice EV Driver
Total distance: 156 miles.
Charged range on departure: 88 miles (31% charge)
Payment method: Apple Pay via iPhone 12 Pro Max
Return round trip back to the start point: 3 h 05 min. Average speed: 50 mph.
Date. Tuesday, 18 May 2021

The sixth case study employs one driver entirely new to EVs. The driver was trained in the EV operation and basic working theory, including familiarity with all controls. The driver was fully insured for the research journey before the commencement of the investigation. This study aimed to observe how an experienced driver who has never driven an EV manages a round trip of 156 miles in a modern all-electric vehicle. One researcher travelled as a rear seat passenger and scrutinised any changes in the driver's habits. As in case study five, the driver's only form of payment was a contactless Apple smartphone using Apple Pay®. The driver was provided with ZapMap [55] to plot a break in the journey mid-point for refreshments and suggested recharge. The driver planned charging options based on each location's claim that contactless payments were available in PAYG Guest mode.

Again, a VW iD3 was acquired for this case study. The driver used an Apple Watch 4 to monitor and measure heartbeat at critical points along the route. These data were then used to measure and correlate anxiety levels throughout the journey.

The 156-mile route used in case study five was duplicated for this study. The driver entered the start, interim and finish coordinates using the in-car satellite navigation system from the Cotswolds to Rugby, then on to Birmingham and finally returning to the start point in the Cotswolds. The total journey distance was 156 miles. The driver and observer departed the Cotswolds at 13:00 h on Tuesday, 18 May 2021. The ambient temperature was 17 °C. Two adults were travelling, comprising one researcher as an observer and one driver. The critical points for the whole journey were recorded using the drivers heart rates and corresponding anxiety levels entered into the table, detailed in graphical form in Table 8.

Table 8. Case study 6. Anxiety levels based on heart rate—VW iD3 EV (Apple Pay only).

Case Study 6		Driver Round Trip	
Key Points on the Journey		Heart Rate	Anxiety Level
1.	Departure—Cotswolds	77	3
2.	Teddington Hands Roundabout—A46—no stop	96	6
3.	Morrisons supermarket—Evesham A46—optional charge point	118	7
4.	Rugby Services—M6 mid-way—charge and refreshment break	107	6
5.	Corley Services—M6—no stop	98	5
6.	Hopwood Park Services—M42—no stop	107	5
7.	Strensham Services—M5—no stop	88	4
8.	Arrival—Cotswolds	69	2

CASE STUDY 7. Route 2.
Round trip from the Cotswolds to Rugby and back via Birmingham—UK.
Vehicle: VW iD3 pure electric hatchback
Experienced EV Driver
Total distance: 156 miles.

Charged range on departure: 86 miles (31% charge)
Payment method: Apple Pay via iPhone 12 Pro Max
Return round trip back to the start point: 3 h 01 min. Average speed: 50 mph.
Date. Wednesday, 19 May 2021

The seventh case study employs one experienced EV driver (D). The driver was trained in the iD3 EV operation and basic working theory, including familiarity with all controls. The driver was fully insured for the research journey before the commencement of the investigation. This study observed how an experienced EV driver manages a round trip of 156 miles in a modern all-electric vehicle. One researcher travelled as a rear seat passenger and scrutinised any changes in the driver's habits. As in case study six, the driver's only form of payment was a contactless Apple smartphone using Apple Pay®. The driver was provided with ZapMap [55] to plot a break in the journey mid-point for refreshments and suggested recharge. The driver planned rapid charging options based on each location's claim that contactless payments were available in PAYG Guest mode.

Again, a VW iD3 was acquired for this case study. The driver used an Apple Watch 4 to monitor and measure heartbeat at critical points along the route. These data were then used to measure and correlate anxiety levels throughout the journey.

The 156-mile route used in case studies five and six was duplicated for this study. The driver entered the start, interim and finish coordinates using the in-car satellite navigation system from the Cotswolds to Rugby, then on to Birmingham and finally returning to the start point in the Cotswolds. The total journey distance was 156 miles. The driver and observer departed the Cotswolds at 13:00 h on Wednesday, 19 May 2021. The ambient temperature was 16 °C. Two adults were travelling, comprising one researcher as an observer and one driver. The critical points for the whole journey were recorded using the drivers heart rates and corresponding anxiety levels entered into the table, detailed in Table 9, highlighted in graphical form in Figure 12, and analysed in Section 4.

The higher anxiety levels among EV drivers resulting from our seven case studies, highlighted in Figures 11 and 12, link with observations and existing data from our previous peer-reviewed study [7]. A structured survey of 282 EV motorway rapid charging EV users found four main areas contributing negatively towards growth in the EV sector (1) rapid charger geographic locations. (2) charger uptime and operability at point of use, (3) restrictive payment process, and (4) rapid charge cost per kWh. Table 10 compares the results from our previous survey revealing anxiety levels of EV users ranging from very satisfied to very dissatisfied, all critical issues that correlate directly with the researcher's findings within the EV long-distance case studies two, three, four, five, and six. The survey results are shown in Table 10. The authors of [7] concentrated wholly on the UK motorway and A-Class UK trunk road network. In contrast, the seven new case studies in this research included a mix of over 570 miles of motorways, dual carriageways, and A-class single lane trunk roads.

Table 9. Case study 7. Anxiety levels based on heart rate—VW iD3 EV (Apple Pay only).

	Case Study 7	Driver Round Trip	
	Key Points on the Journey	**Heart Rate**	**Anxiety Level**
1.	Departure—Cotswolds	71	2
2.	Teddington Hands Roundabout—A46—no stop	76	3
3.	Morrisons supermarket—Evesham A46—optional charge point	88	4
4.	Rugby Services—M6 mid-way—charge and refreshment break	85	4
5.	Corley Services—M6—no stop	76	3
6.	Hopwood Park Services—M42—no stop	77	3
7.	Strensham Services—M5—no stop	79	3
8.	Arrival—Cotswolds	68	2

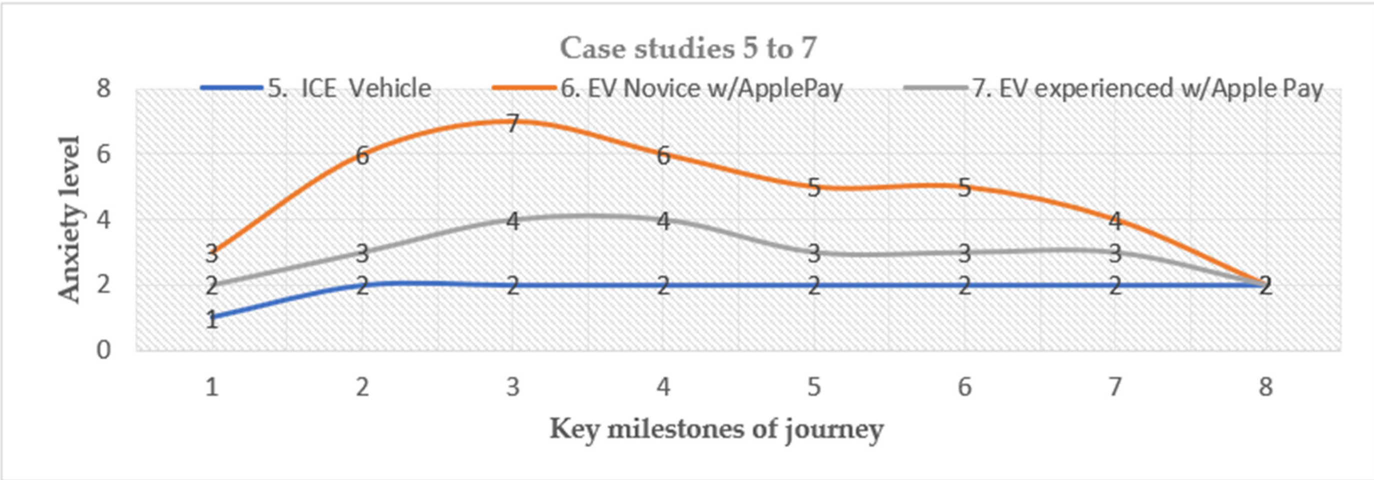

Figure 12. Anxiety levels for case study 4, 5, and 7. EV drivers using Rapid Chargers in Critical Service Station Locations in the UK.

Table 10. Dominant outcomes from each survey question [7].

UK Motorway EV Rapid Charging User Survey					
	Questions				**Subject**
	Very Satisfied	**Satisfied**	**Dissatisfied**	**Very Dissatisfied**	
Q1		76%			Charger availability
Q2		62%			Charger speed
Q3			49%		Charger operability
Q4				58%	Charge cost
Q5			62%		Charger locations
Q6	51%				Connector availability
Q7	51%				EV range
Q8		75%			Overall experience
Q9			52%		Payment process
CGA		34%			Satisfaction average

3.1. Case Study and Recent User Survey Summary Data

It is impossible to precisely reproduce each route due to variables that cannot be replicated on the day. Among the most important of these is ambient temperature, which can adversely affect EV battery use. Other factors may include weather conditions such as wind, rain or snow, and general traffic conditions or disruption, all of which may affect the range of an EV.

3.2. Discussion

In Tables 11 and 12, the case studies reveal that an EV driver's experience is more traumatic than a conventional ICE vehicle driver, with far higher anxiety levels being measured throughout their journey. This result is supported by recent survey [7] of drivers across major service stations on the UK network, revealing that most EV drivers considered charge cost, charge point operability, charge point location, payment process, and access were significant areas of dissatisfaction. Our results suggest that CPT exists because of a significant correlation between increased heart rate at key journey points. Moreover, the literature confirms a significant link between heart rate and anxiety levels [52]. We argue that unless urgent interventions are implemented to alleviate this growing EV user issue, then the introduction of enforced sector regulation to improve overall parity with ICE fuel service stations should be investigated.

Table 11. Case studies 1, 2, and 3 anxiety level comparison table.

Key Data Points on the Journey	Case Study 1 (ICE)	Case Study 2 (EV)	Case Study 3 (EV)	Case Study 4 (EV)
1. Departure—Cotswold's	1	3	2	2
2. M5 J.11	2	4	3	3
3. Cullompton Services	2	4	4	3
4. A30 garden centre	2	6	3	4
5. Supermarket charger	2	6	3	3
6. Cornwall Services	2	6	3	3
7. Destination arrival—Cornwall	2	4	3	3
8. Departure back	2	4	3	3
9. Cullompton services	2	4	3	2
10. Arrival—Cotswold's	1	2	2	2
Average heart rate	67.9 BPM	90.8 BPM	78.2 BPM	76.6 BPM
Combined mean average anxiety levels	1.80 Experienced	4.3 Novice	2.9 Novice	2.8 Experienced

Table 12. Case studies 4 and 5 anxiety level comparison table.

Key Data Points on the Journey	Case Study 5 (ICE)	Case Study 6 (EV)	Case Study 7 EV
1. Departure—Cotswold's	1	3	1
2. Toddington Services—A46	2	6	2
3. Morrisons Evesham	2	7	2
4. Rugby Services—M6 mid-way	2	6	2
5. Corley Services—M6	2	5	2
6. Hopwood Park Services—M42	2	5	2
7. Strensham Services—M5	2	4	2
8. Arrival—Cotswold's	1	2	2
Average heart rate	67.2 BPM	93.6 BPM	70.4 BPM
Combined mean anxiety levels	1.75 Experienced	4.75 Novice	1.87 Experienced

4. Results, Analysis, and Discussion

The sample for this study included experienced ICE drivers, novice EV drivers, and an experienced EV driver. The rationale for the mix of driving experience was to monitor and validate any differences between the three categories, travelling the same route under the same conditions, with only driver experience and vehicle type being variables (Table 1). Heartrate was captured and logged via a cloud-based database, using a 4G mobile link, by the minute throughout each journey.

Before analysing the data, we manually checked the benchmark novice EV drivers BPM as EV range dropped before arriving at each charging station. From the data and noting the driver's concerns regarding range en route, BPM and anxiety heightened as the EV range lowered before arrival at the charging station on both routes. These data, coupled with the driver's changing behaviour and growing anxiety, confirmed that, even though modern EVs such as our test car had a range above 260 miles, our novice EV drivers were still experiencing reasonably high levels of range anxiety. This was also confirmed through *t*-test correlation analysis that can be observed in detail within Appendix B.

This initial case study prompted the design of a field-based theoretical framework (Figure 2) to map not just the elements of CPT, but to illustrate how range anxiety still forms a significant component of the EV driving experience and behaviour, despite the ever-increasing mileage ranges of newer EVs. We see from the data that although range anxiety is the catalyst for increased EV driver anxiety levels amongst novice drivers, there was a significant increase in anxiety once the driver had entered the charging zone.

We noted that anxiety levels lowered once a successful charging cycle commenced. Conversely, when the novice EV drivers entered a charging zone and encountered one of the three barriers to charging that contribute to CPT (Figure 2), then significant increases in anxiety were noted (Figures 13 and 14). The data confirm a significant correlation between heightened EV driver anxiety and barriers to charging encountered at key milestone five in route one (Figure 13). The novice EV driver continued to the next charging station in a state of higher anxiety. We argue that this is a combination of CPT experienced at the charge point and then displaying heightened range anxiety onward. Again, this phenomenon is observed with a clear correlation between higher anxiety and barriers to charging experienced at key milestone three in route one using a novice driver (Figure 14).

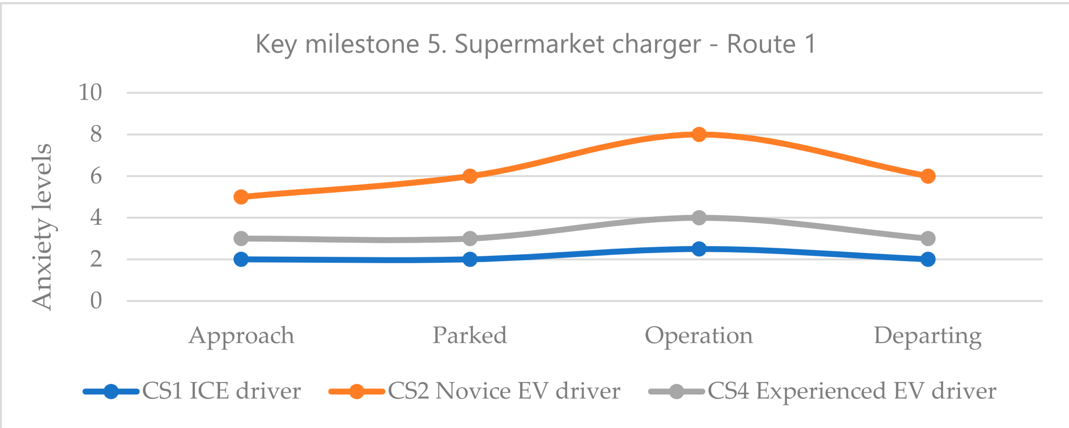

Figure 13. Comparative analysis of EV driver anxiety state at an inoperable charge point.

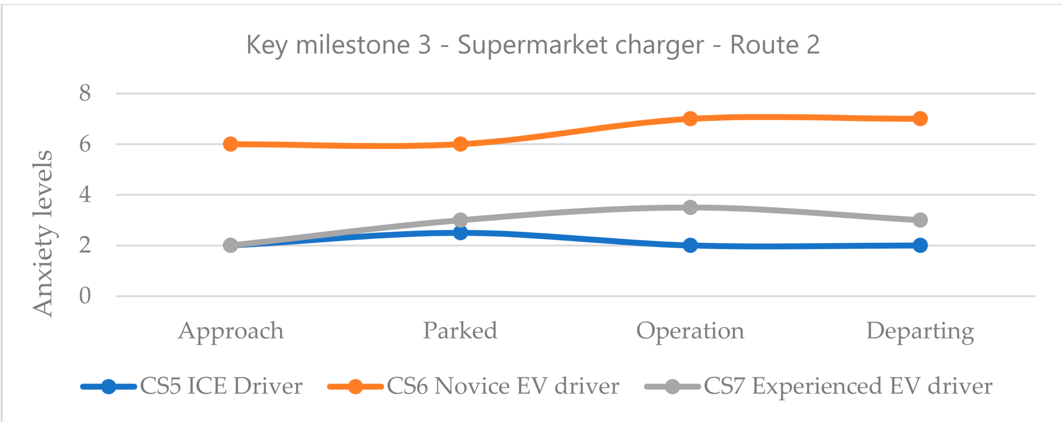

Figure 14. Comparative analysis of driver anxiety state at an inoperable charge point.

For the experienced EV driver, the levels of range anxiety were still heightened en-route, but at a markedly lower level overall when entering the charging zone compared to the novice drivers. This suggests that as experience and familiarity with an EV develops, range anxiety and CPT levels are correspondently lower as confidence in the vehicle increases.

To confirm this theory, we further investigated our data. We observed the drivers state of anxiety when approaching a charge point, parking up, plugging in, experiencing a trouble-free charge, then continuing the journey on departure. We first investigated key milestone three at the M5 Cullompton services on route one, inbound journey (Figure 15). This time we noted a fractional, insignificant rise in the ICE drivers state immediately before refuelling. In contrast, there was no further rise on the journey approach in the driver's state of anxiety. Once refuelling and charging for all drivers were in progress, there was a significant drop in anxiety for both novice and experienced EV driver's at and after recharging. This confirms our hypothesis that where no barriers to charging exist, then EV drivers state of anxiety is consistently always lower in our case studies.

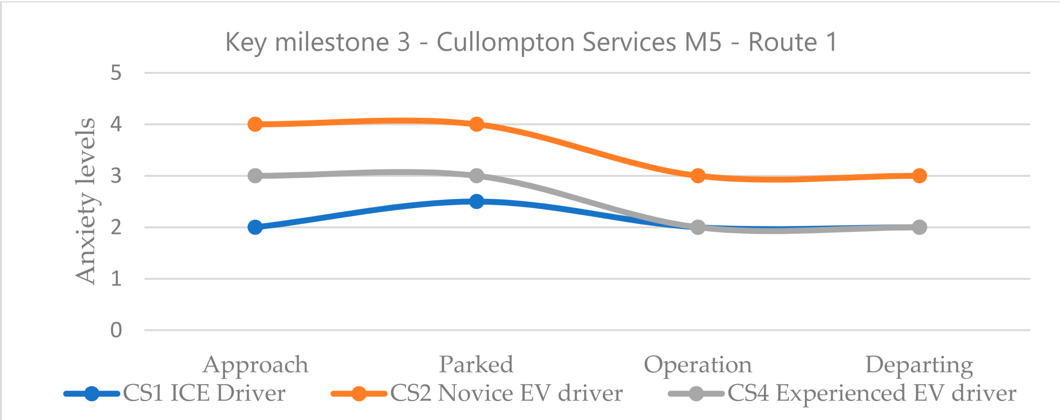

Figure 15. Comparative analysis of anxiety state of drivers at an operable charge point.

Finally, we investigated the data from key milestone four, Rugby services M6 on route 2 (Figure 16). This time we noted no rise in the ICE driver's state immediately before refuelling. Once refuelling and charging for all drivers was in progress, there was a significant drop in the state of anxiety for both novice and experienced EV drivers. Furthermore, after recharging, particularly for novice EV drivers, their anxiety level dropped markedly, demonstrating increasing confidence in their vehicle. This confirms our hypothesis that where no barriers to charging exist, the EV drivers state of anxiety is always lower in our case studies. Even after refuelling, the novice EV drivers' state of anxiety was higher than the experienced EV and ICE driver, confirming that prolonged EV driving experience reduces anxiety relating to both vehicle range and CPT.

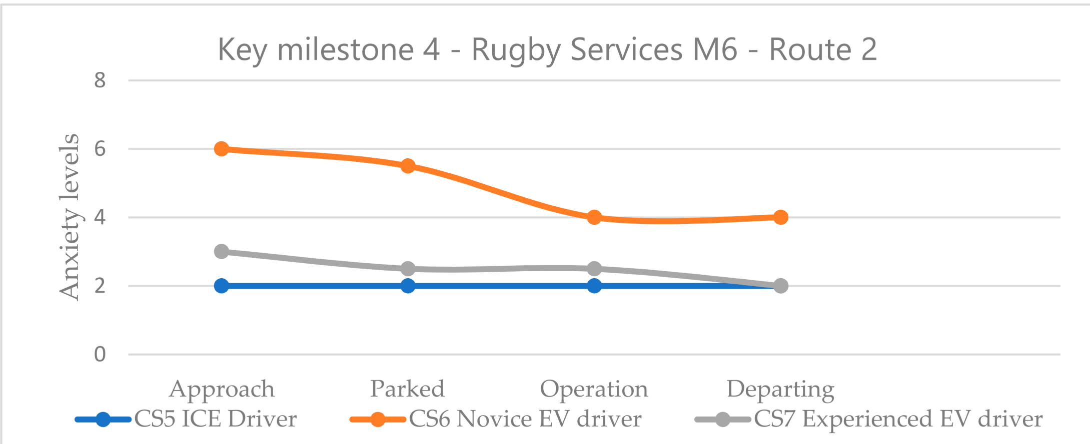

Figure 16. Comparative analysis of anxiety state of drivers at an operable charge point.

The descriptive results in Appendix B indicate that drivers in route two had a higher average heart rate than drivers who undertook route one. The main reason for this is that route one drivers started the journey with a full charge, whereas, on route two, we purposely limited both ICE and EV vehicles with just enough fuel or charge to make it to the mid-point stop at Rugby Services, forcing a refuel or recharge.

Finally, the ICE driver with more than ten years of experience with long-distance driving rarely encountered the same levels of anxiety experienced by either type of EV driver. One of the main reasons behind this phenomenon is because the ICE vehicle's range enabled it to travel the total round-trip distance of the south-westerly route with fuel to spare. Moreover, on the shorter northern route two, even faced with just enough fuel to complete half of the trip, the ICE driver's confidence maintained a constant low state of anxiety. This lack of range anxiety in an ICE vehicle is almost certainly because the ICE fuelling network is more than 99% reliable [15] and thus builds confidence in a driver's ability to refill on-demand. Moreover, due to tight regulation on opening hours, crewed fuelling stations and highly regulated service level agreements on uptime and operability, there was practically no heightened anxiety in this cohort of drivers. To date, there is little regulation across the UK network of EV rapid charging stations.

Although our research points to increased anxiety at the charge point, and this in our analysis points to CPT, further in-depth research should be conducted to establish that CPT is more than extended range anxiety since we know from our data that in all cases, anxiety rises at the charge point zone when some form of operational problem creates a barrier to charge point use. This study is the catalyst for further investigation.

By providing insight into CPT, this research illuminates potential EV owner's preferences regarding charging station infrastructure. Our results indicate that the location of charging stations heightened a state of anxiety, and for this reason, the charging stations should be closer to each other to reduce range anxiety. This can lead to higher EV growth by encouraging more vehicle users to purchase an EV versus a traditional ICE vehicle. Taking this into account, we argue that our investigation covers the CPT phenomenon from four different perspectives—location, accessibility, payment access, and operability.

Using the data collected via the case studies and user surveys described in Section 4, we answer our research questions introduced in Section 1 as follows:

- Future EV owners will require a charging station infrastructure denser than the current ICE refuelling infrastructure due to an average EV taking up to ten times longer to refuel [7].
- As EVs replace ICE vehicles, there will be a surplus of traditional ICE fuelling stations due to lowering demand for their services. These may be converted to high power EV rapid charging stations to reduce the EV charge point deficit, subsequently alleviating current anxiety levels amongst EV drivers, thus lowering CPT.
- For future studies, we plan to increase the survey participant pool with a more focussed and targeted audience by including drivers who are either undecided about or on the cusp of making an EV purchase. This phase is critical in understanding and quantifying that the CPT phenomenon is not only a significant issue and potential barrier to EV growth but should be a requirement to credibly remodel charge point infrastructure planning as an essential element to driver EV acceptance.

4.1. Distribution of Charge Points and CPT

The distribution of charge stations across the UK reveals that the charging infrastructure is not well-developed. The uneven distribution of charging infrastructure reported by the DfT [19] is consistent with public EV charging infrastructure observations. Specifically, the DfT argued that there are no predefined criteria for infrastructure installation, and manufacturers have relied on a 'postcode lottery' approach leading to *user anxiety*. Beyond the uneven distribution of rapid charge infrastructure, the manufacturer's low transition to electric mobility and low EV mileage range indirectly contribute to *CPT*, discussed in Section 5.2.

4.2. Manufacturer's Low Transition to Electric-Powered Mobility

Current industry data shows that established manufacturers fulfilled the limited EV development of EVs. This phenomenon is reinforced by a comparative analysis of the market share and the state of growth of carbon fuel-powered vehicles. According to SMMT data [37], the principal UK manufacturers largely maintained their market share in the 2018/2019 financial year. In addition, the number of non-EVs sold was incomparable to the ratio of EVs traded, noted by SMMT [37]. The Business, Energy, and Industrial Strategy Committee of the House of Commons (HoC) similarly established that manufacturers showed varying commitment levels to electric mobility [1]. Both Volkswagen and Mercedes committed to achieving a 25% transition to EVs by 2030, seen as unsatisfactory within the UK government report [1]. Volvo and Toyota have announced their intentions to transition to 50% within this period by 2030. Porsche and Jaguar were the only exceptions, with both companies proposing a 100% transition by 2030 [1]. This inconsistent commitment to the electrification of the powertrain could contribute to a slowdown in the adoption of EVs in the UK market, considering that Volkswagen and Mercedes have a combined market share of 17% as of 2019 [37]. The above observation is supported by the fact that limited EV development would make the installation of brand-specific charging infrastructure economically unsustainable. Further research is required to ascertain the extent to which commitment to electrification slowed EV growth in the UK.

The level of rapid-charging network growth in the UK is comparable to similarly established European markets, as shown in Figure 17 below. Conversely, the UK lags China, Norway, and the USA in the number of vehicles adopted but are similar as a per capita ratio to China and the USA. Furthermore, the UK, USA, Norway, and China are market leaders in EV technologies and vehicle development. This problem could be addressed if stakeholders collaborate to develop the charging infrastructure jointly. Nevertheless, private sector efforts are inadequate without government-supported policy support changes by the government. According to Hirst [1], examples of such policies include EV registration tax exemptions, VAT exemption at the point of purchase, ongoing zero road tax, access to free municipal parking and elimination of tolls, parking, and bridge fees for EVs. We concur with Hirst that such policy changes would incentivise charge point operators to increase charge station's deployment.

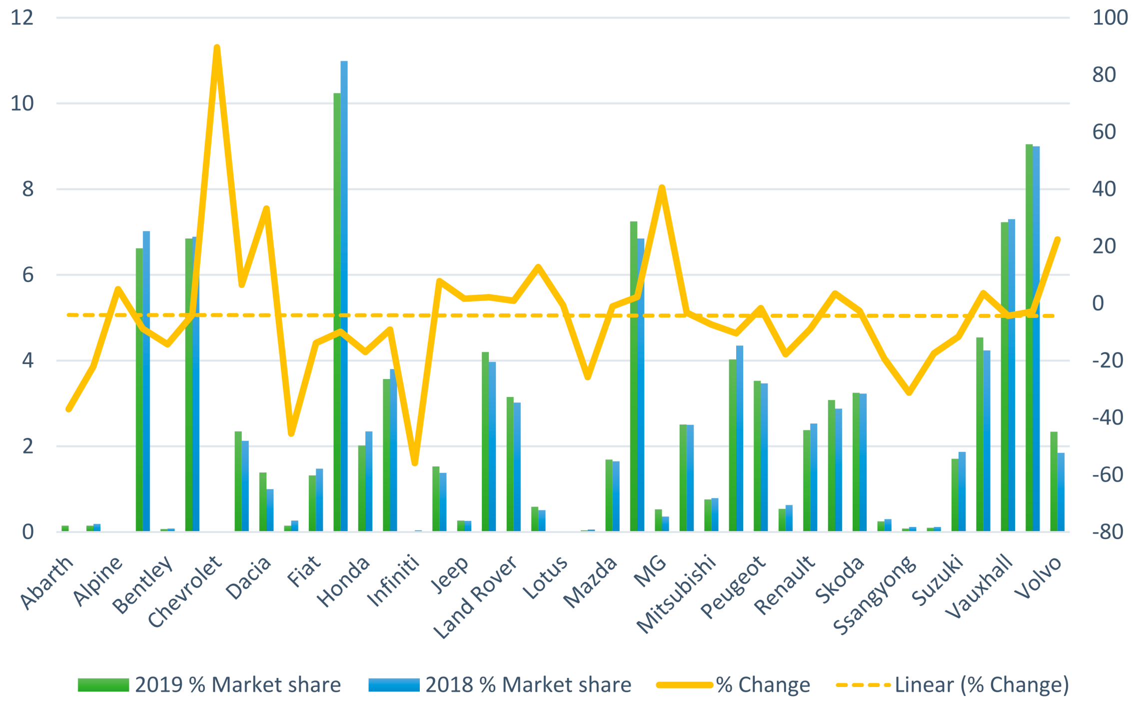

Figure 17. Market share % in the standard vehicle segment (2019 versus 2018).

5. Recommendations

Our recommendations are informed by best practices applied in the UK, US, China, and Norway. All four countries act as a reference point and benchmark since they are global leaders by EV volume per capita in EV technologies.

First, policymakers should calculate the total number of EVs on the road, including forecasts up to 2030. Second, EV power requirements and regional variations in the power demands should be determined. Analysing the power requirements will help determine the charge duration and the number of chargers needed per square mile, and how the chargers are categorised. Thirdly, more government intervention should regulate the UK's rapid charging network's operation, availability, and location. Fourthly, there needs to be more investment from government and manufacturers to incentivise consumers toward the transition to an electric future. The Norwegian model is a testament to how inducements can stimulate the transition towards a 100% electric target. Norway currently has the world's highest number of EVs per capita, totalling 55.9% of the total car market in 2020 [15]. We argue that adopting the four-point analysis above will, if adopted, reduce the incidence of CPT by removing anxiety pinch points that many EV drivers experience now [7].

5.1. Limitations

The primary drawback of this investigation is the overall lack of published literature concerning CPT. Although we conducted new, relevant, and current research through case studies and user surveys, our results are limited by sample size. Bodies such as SMMT, International Council on Clean Energy, Deloitte, and other stakeholders have published various EV reports. Still, some of these reports and data sets are not updated and may be biased toward the intended reader. For example, information published between 2010 and 2017 does not reflect the current state of the EV sector because the industry is dynamic and continuously evolving. Additionally, there was an inherent risk of bias in published data by EV manufacturers, partners, and regulators with a vested interest in the industry. These limitations demonstrate the need for further primary research, and it is suggested that this will be an ongoing necessity in this fast-moving, dynamic market.

These proposals should also be employed to test against the UK government's latest target of banning all new petrol and diesel-engined cars by 2030. Moreover, in a report by Deloitte [47], almost one in four EV drivers would not have access to a driveway or a private charging station. This position may exacerbate CPT unless it is effectively addressed by installing new roadside public rapid charge stations. Even though there is a consensus on the need to develop a contiguous nationwide network of rapid-charging stations [3,31,46] and to transition from the current postcode lottery system [1], there is no long-term framework for funding or regulation. Concerns about funding transition should be addressed since the installation of charging infrastructure is hugely capital intensive.

5.2. Statement of Significance

The findings drawn from this research may provide important implications for policy-makers, EV manufacturers, charge point operators (CPO's), and EV owners by taking stock of the progress made in EV manufacturing and assimilation into the automotive sector, the prospects for growth, and the barriers linked to the absence of sufficient operable and available charging stations with equivalence to fossil fuel station access. Furthermore, the investigation of the link between CPT and the growth of EVs in the UK may help inform future decision-makers in the development of nationwide contiguous charging infrastructure, satisfying the requirements of EV consumers, accelerating user acceptance to make the change to an EV, and subsequently driving growth by reducing current barriers to adoption and use of EVs.

6. Conclusions

The following observations were made from this investigation. First, there is a level of evidence in our research and analysis regarding the link between CPT that, if ignored, may act as a barrier to EV growth in the UK due to significant EV user dissatisfaction in fundamental areas [7]. Both primary case studies and surveys revealed user ambiguity in the following five areas. (1) range anxiety, an element that we had discounted initially but still intensely exists, (2) rapid charger locations, or lack of, (3) point of use availability, (4) disparate payment processing and variable charge costs, and (5) general operability (Figure 1). The evidence is informed by industry statistics, research and our seven case studies correlated with previously obtained survey results [7]. Secondly, we found that the level of anxiety lowers with experience and vehicle familiarisation. Finally, the consumer concerns are further validated by the often-random network planning of rapid charger deployment, due chiefly to grid availability rather than user-accessible trunk route location [2]. We believe there should be a government-funded National Network Planning Committee (NNPC) to eliminate the current barriers facing EV drivers using the UK rapid charging network. This will ensure that before random EV charging locations are granted local planning permission, every project must add tangible value to the overall national network. This will prevent charge point blackspots or, conversely, excess charge points in one area, ensuring contiguous coverage nationwide, comparable to the current ICE fuelling station network.

Founded on our findings proving a direct correlation between heart rate and anxiety levels, our case studies revealed a worrying upward trend in EV driver anxiety levels caused by infrastructure pinch points, such as lack of available chargers and payment processing complications. Therefore, this research to date through our detailed data analysis employing a *t*-test and correlation analysis (Appendix A), confirms our hypothesis that there is a critical CPT link to the EV user anxiety levels experienced in our case studies and the dissatisfaction of EV users in four key areas, revealing significant increases in anxiety levels compared to corresponding journey range anxiety. However, a more stringent investigation covering a much larger sample size may confirm or refute these findings.

From an engineering and technological perspective, it can be argued that there is a casual connection between technical limitations in EV energy storage systems (energy density versus power density) and CPT because the power limitations in level 1 and 2 Rapid charging systems are linked to the constraint of available technologies. In brief, the central research hypothesis is validated by our current data. Our case studies, supported by our recent user survey of 282 motorway EV drivers, revealed a correlation between the four main user survey areas of dissatisfaction [7] and the high anxiety events witnessed in our seven case studies, confirming a clear link between anxiety or trauma levels experienced by EV drivers compared to ICE drivers. This is the first study of its kind and one which will hopefully lead to substantial future investigations. We argue that CPT will increase amongst EV users and propagate adverse publicity through traditional and digital media channels. We also believe that a slow-down in growth could be reversed by intervention through governmental regulation and harmonisation in standards for all charge point operators [7]. This would bring parity of EV user experience toward that of regular ICE drivers.

In general, this research has advanced the current body of knowledge on EV users' post-acquisition by exploring a critical theme beyond the availability and service of the UK EV rapid charge network and mileage range of EVs.

As this study is the first example of an investigation to link four constituent barriers to EV growth that together results in a new phenomenon identified as CPT, we suggest that further research should focus on the most critical negative EV user issue—to reverse the practice of continuous deployment of rapid chargers in grid friendly outlying areas, rather than locating rapid charge points in areas where they are most needed to fulfil EV users' needs on main trunk routes. We argue that this can only be remedied through government intervention, design, and enforcement of new regulations. We encourage deploying emerging AI-driven technology to integrate with grid availability and control rather than overlooking this vital issue.

More complete and accurate documentation, including additional case studies during peak summer months, with higher traffic volumes, higher ambient temperature, and a more detailed driver profile (i.e., age, sex, and physical fitness), may produce a more comprehensive assessment of individual circumstances, leading to complete knowledge of the processes affecting long-term trauma levels in EV drivers. Once we have a clearer understanding of the relationship between CPT and factors such as age, length of ownership, and familiarity with the EV, measures can be designed and implemented to improve the UK's EV long-distance commuting user experience. This would include a ubiquitous pay-as-you-go payment system for all contactless payment types, regardless of whether the EV user is a brand member of the charge point operator (CPO).

Furthermore, we suggest a legally binding service level agreement between the CPO and the Department for Transport (DfT) regulator mandating a minimum uptime for operability and accessibility of all users. Additionally, thousands more rapid charge points are required across all UK main trunk routes. We found that the average time spent at a charge point was approximately 50 min–1 h during our case study observations. We also noted that most UK motorway service stations had only two rapid chargers (two exceptions had four). Given that the UK government is banning the sale of diesel and petrol cars by 2030, the number of rapid charge points on main trunk routes will need to increase at least ten-fold to avoid major queuing at service stations and subsequent delays in an EV user's journey, leading the investigators to pursue ongoing research in this area.

In the short to medium term, whilst we fully understand that there will be a penalty of additional upfront capital costs in developing dedicated EV service areas; for instance, we believe this can be offset by greater use of the charging station and increased footfall in on-site amenities due to locality, convenience, and access to main trunk routes. If implemented, our findings and recommendations point to a significant correlation between lower CPT and greater EV user satisfaction, indicating an acceleration in the adoption of EVs by mitigating current barriers to growth and promoting incentives in line with the government "Road to Zero" target. In conclusion, we suggest all stakeholders, including manufacturers and government, should be fully invested in reducing CPT since it may slow EV adoption and could be a significant barrier to growth in the EV sector. We believe an acceleration of current rapid charger deployment will also diminish current levels of range anxiety due to increased rapid charging capacity across the UK.

Author Contributions: Conceptualization, K.C. methodology, K.C.; validation, K.C. and S.A.M.; formal analysis, K.C.; investigation, K.C.; resources, K.C. data curation, K.C.; writing—original draft preparation, K.C.; writing—review and editing, K.C. visualization, K.C.; supervision, S.A.M.; project administration, K.C.; S.A.M. All authors have read and agreed to the published version of the manuscript.

Funding: We confirm that this research has received no funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Appendix A.1 Route 1—4 Case Studies Using Different Drivers for Each Trip

Table A1. Case study 1. Journey anxiety levels ICE SUV. Experienced ICE driver and observer.

Key Points on the Journey		Driver 1 Outbound		Driver 2 Inbound		Driver Observations
		Heart Rate (HR)	Anxiety Level	Heart Rate (HR)	Anxiety Level	
1.	Departure—Cotswolds	61	1			Driver is calm and focused. Low BPM.
2.	M5 J.11	72	2			Driver has slightly higher BPM but remains calm
3.	Taunton Deane Services	66	2			Driver exhibits constant BPM and remains calm
4.	Arrival and return—Cornwall	66	2	71	2	Driver exhibits constant BPM and remains calm
5.	Taunton Deane Services			73	2	Driver exhibits constant BPM and remains calm
6.	Arrival—Cotswolds			63	1	Driver arrives calm and focused. Low BPM.

Table A2. Case Study 2—Novice EV driver—including one researcher as passenger and observer.

Key Points on the Journey		Driver Outbound		Driver Inbound		Driver Observations
		Heart Rate (HR)	Anxiety Level	Heart Rate (HR)	Anxiety Level	
1.	Departure—Cotswolds	76	3			Driver has above average BPM and appears slightly anxious.
2.	M5 J.11	87	4			Driver appears more anxious as the car approaches busy motorway. Higher BPM.
3.	Cullompton Services	89	4			Still significantly high BPM. Driver concerned with range and very concerned that identified services were not found.
4.	A30 garden centre	107	6			Very anxious that premises were closed for the day with no available charger. Significant rise in BPM and demonstrating anxiousness on the EVs range ability.
5.	Supermarket charger	110	6			Again, very concerned that charge point was not available. Constant high BPM pointing to significant range anxiety and CPT due to inoperable charge points
6.	Cornwall Services	107	6			Maintaining range ability of EV en route to charge point. On arrival, chargers required subscription. Driver is now very concerned about reaching destination even though cars range has 30 miles excess charge to destination. Comments that he is apprehensive about range. Still in eco mode. High BPM.
7.	Destination—Cornwall	88	4			Although higher than average BPM, the driver is now much calmer after arriving at the destination without further charge.

Table A2. *Cont.*

Key Points on the Journey	Driver Outbound		Driver Inbound		Driver Observations
	Heart Rate (HR)	Anxiety Level	Heart Rate (HR)	Anxiety Level	
8. Departure back			85	4	Day 2, and EV now fully charged, higher BPM suggests driver is still anxious, even though there is a charge stop mid-way.
9. Cullompton services			88	4	Refreshment stop only as chargers require a subscription. Driver is still anxious that he may not get to the destination without further charge, despite excess range displayed. Driver switches to eco-mode.
10. Arrival—Cotswolds			71	2	Driver very relieved to arrive at home base. BPM is now much lower

Table A3. Case Study 3. Novice EV driver—including one researcher/observer (with cards and cash).

Key Points on the Journey	Driver 1 Outbound		Driver 2 Inbound		Driver Observations
	Heart Rate (HR)	Anxiety Level	Heart Rate (HR)	Anxiety Level	
1. Departure—Cotswolds	67	2			Driver BPM is steady and reading just above previously measured standing BPM. Commented that he felt much more confident taking both cash and cards for payment.
2. M5 J.11	77	3			Slight rise in BPM as we approach major motorway.
3. Cullompton Services	86	4			Arrived at the service station. Drivers BPM was high en-route. The rapid charger works successfully, and BPM is lowering.
4. A30 garden centre	78	3			Now the car is fully charged again, we monitored the driver's BPM at this key point. Calm and focused
5. Supermarket charger	81	3			Calm at this point when reading was taken. No need to stop as excess charge remaining to destination. Still anxious.
6. Cornwall Services	84	3			The driver opted not to stop at this service station, but the observer took BPM. Calm and focused
7. Destination—Cornwall	76	3			Driver calm and commented 'relief at arriving', despite having 111 miles of range remaining. BPM above average
8. Departure back			78	3	Leaving with 111 miles range, the driver knew that we had to stop mid-way and appeared slightly anxious re: range.
9. Cullompton services			83	3	On arrival at the service station, the car had 15 miles range left. The driver commented that he was concerned but knew he would make the station with excess charge to spare. Mid BPM
10. Arrival—Cotswolds			71	2	The driver's last BPM check confirmed that with half a charge remaining, there was no anxiety at this point.

Table A4. CASE STUDY 4. Experienced EV driver—including one researcher/observer with cash and cards.

Key Points on the Journey		Driver 1 Outbound		Driver 2 Inbound		Driver Observations
		Heart Rate (HR)	Anxiety Level	Heart Rate (HR)	Anxiety Level	
1.	Departure—Cotswolds	65	2			Driver BPM is steady and only just above previously measured standing HR. Driver was calm and looking forward to the trip.
2.	M5 J.11	77	3			Slight rise in BPM as we approach major motorway. Driver appears calm.
3.	Cullompton Services	73	3			Constant BPM as we enter the service station for break and refill. Attempted to charge car, but all four chargers are not accepting cards. Driver appeared calm with more range than destination requires. The driver said, 'he was not concerned'. He switched the car to eco mode for maximum economy and proceeded to the next charge point. Although displaying signs of anxiousness.
4.	A30 garden centre	78	4			Again, although arriving slightly earlier than the previous trip, the centre was closed and locked to the public. The driver was calm and proceeded to the next charge point.
5.	Supermarket charger	81	3			Our previous encounter with this charger required membership. The driver was calm at this point when reading taken and proceeded to next service station.
6.	Cornwall Services	84	3			The driver opted not to stop at this service station, knowing it required membership, but the observer took BPM. Driver still calm and focused.
7.	Destination—Cornwall	76	3			When we arrived at the destination point, the driver commented that the car still had 39 miles of range remaining. He said he was calm and happy to have finished the long journey. BPM was taken, although still well above standing HR suggesting signs of anxiety.
8.	Departure back			78	3	Leaving with a full charge, the driver knew that he could make the journey in one go. Although we had a planned refreshment and charge stop at Cullompton services. BPM was just above average, suggesting slight anxiety.
9.	Cullompton services			83	2	On arrival at the service station, the car had 144 miles range left. The driver commented that he was confident he would make the station with excess charge to spare. He found that the chargers would still not accept a card for payment. Very calm and focused as he started his last 102 miles in eco mode.
10.	Arrival—Cotswolds			71	2	The driver's last BPM check confirmed that with 41 miles remaining, there was almost no anxiety, and he was very calm and happy to be back at home base. BPM was slightly above the average resting rate.

Appendix A.2 Route 2—Using Different Drivers for Each Trip

Table A5. Case study 5. Journey anxiety levels—one experienced ICE driver and researcher/observer.

	Key Points on the Journey	Heart Rate (HR)	Anxiety Level	Driver Observations
1.	Departure—Cotswolds	68	1	Driver is calm and focused. Low BPM.
2.	Teddington Hands Roundabout—A46—no stop—this is a key HR observation point.	74	2	Slight rise in drivers BPM but remains calm
3.	Rugby Services—M6 mid-way—charge and refreshment break	70	2	Driver remaining calm and focused. As we approach the midway point, driver has a Steady BPM
4.	Corley Services—M6—no stop—this is a key HR observation point.	67	2	Driver is calm and focused. Steady BPM
5.	Hopwood Park Services—M42—no stop—this is a key HR observation point.	69	2	Driver remains calm. Steady BPM
6.	Strensham Services—M5—no stop—this is a key HR observation point.	73	2	Driver remains calm. Steady BPM
7.	Arrival—Cotswolds	72	2	Calm and focused. Steady BPM

Table A6. CASE STUDY 6. EV—Journey anxiety levels—one novice EV driver and researcher/observer.

	Key Points on the Journey	Heart Rate (HR)	Anxiety Level	Observations
1.	Departure—Cotswolds	77	3	Slightly high BPM on departure but driver appeared calm.
2.	Teddington Hands Roundabout—A46—No stop—this is a key HR observation point.	96	6	High HR and very concerned about remaining range but always remained focused. Driver did not switch the car to eco mode as suggested.
3.	Morrisons supermarket—Evesham A46—optional charge point	118	7	On approach, the driver's BPM reached 118. Driver was very anxious on arrival because charger was not available for use. BPM remains high at this stage. The driver commented that he was very concerned about making it to the mid-way charging point due to low range but remained focused.
4.	Rugby Services—M6 mid-way—charge and refreshment break	107	6	Still anxious. BPM level on approach is 107 but relieved that charger is operable, and the car is now fully charged. BPM was very high, showing significant anxiety at this stage.
5.	Corley Services—M6—no stop—this is a key HR observation point.	98	5	BPM dropped, but the driver commented that he was still not completely confident with cars range despite full charge.
6.	Hopwood Park Services—M42—no stop—this is a key HR observation point.	107	5	BPM still moderately high. Driver comments that he still lacked confidence in the cars range ability.
7.	Strensham Services—M5—no stop—this is a key HR observation point.	88	4	As we near our home base, drivers BPM dropping, and anxiety noticeably lessens
8.	Arrival—Cotswolds	69	2	Much lower BPM as we reach home base. Driver commented that he was relieved and relaxed after the round trip.

Table A7. CASE STUDY 7. EV—Journey anxiety levels—one experienced EV driver and researcher/observer.

	Key Points on the Journey	Heart Rate (HR)	Anxiety Level	Observations
1.	Departure—Cotswolds	77	2	BPM is just above average. Driver appears calm.
2.	Teddington Hands Roundabout—A46—no stop—this is a key HR observation point.	96	3	Calm, but BPM is rising as we approach the first charging stop.
3.	Morrisons supermarket—Evesham A46—optional charge point	118	4	BPM rises when driver discovers that charger cannot be used without a subscription. Although, the driver still appeared calm and focused.
4.	Rugby Services—M6 mid-way—charge and refreshment break	107	4	BPM maintains a similar mid-rate on arrival at mid-point charging stop
5.	Corley Services—M6—no stop—this is a key HR observation point.	98	3	Driver's BPM lowers once the EV has been fully charged
6.	Hopwood Park Services—M42—no stop—this is a key HR observation point.	107	3	Driver appears calm. Although, drivers BPM is above the resting rate.
7.	Strensham Services—M5—no stop. This is a key HR observation point.	88	3	Again, no significant change in BPM, appearing calm and focused.
8.	Arrival—Cotswolds	69	2	Drivers HR drops on arrival to home base at just above resting rate. Driver commented, 'he enjoyed the trip'.

Appendix B

Appendix B.1 Data Analysis and Results

Appendix B.1.1 Descriptive Analysis Per Case Study

A descriptive analysis was conducted to examine the average heart rate and anxiety levels for each case study, and overall (all case studies and routes 4 combined), utilising the mean, standard deviation, minimum, and maximum statistics to conduct the analysis. The results established from the analysis undertaken is presented in Table A8 below. The highest rank represents the lowest BPM and anxiety level, and the lowest rank represents the highest BPM and anxiety levels

Appendix B.1.2 Heart Rate Per Case Study

Considering the results presented in Table A8 above, the minimum heart rate level for case study one driver was 61, while the maximum was 73. The driver in case study one had an average heart rate of 67.43 with a standard deviation of 4.65 measured across seven measuring points along the departure and return route.

Route 1. Southwest Round Trip

The minimum heart rate level for case study two drivers was 71, while the maximum was 110. The driver in case study two had an average heart rate of 90.80 with a standard deviation of 13.21 measured across ten measuring points along the departure and return route.

The minimum heart rate level for the case study three driver was 67, while the maximum was 86. The driver in case study three had an average heart rate of 78.10 with a standard deviation of 5.86 measured across ten measuring points along the departure and return route.

The minimum heart rate level for case study four driver was recorded as 65, and the maximum was 84. The driver in case study four had an average heart rate of 76.60 with a standard deviation of 5.78 measured across ten measuring points along the departure and return route.

Table A8. Descriptive Analysis of Study Variables Per Case.

Case Study		N	Mean	SD	Min	Max	Rank
1							
	Heart Rate	7	67.43	4.65	61	73	7
	Anxiety Level	7	1.71	0.48	1	2	7
2							
	Heart Rate	10	90.80	13.21	71	110	2
	Anxiety Level	10	4.30	1.34	2	6	2
3							
	Heart Rate	10	78.10	5.86	67	86	3
	Anxiety Level	10	2.90	0.56	2	4	4
4							
	Heart Rate	10	76.60	5.78	65	84	5
	Anxiety Level	10	2.80	0.63	2	4	5
5							
	Heart Rate	7	70.43	2.64	67	74	6
	Anxiety Level	7	1.86	0.38	1	2	6
6							
	Heart Rate	8	95.00	16.37	69	118	1
	Anxiety Level	8	4.75	1.67	2	7	1
7							
	Heart Rate	8	77.50	6.61	68	88	4
	Anxiety Level	8	3.00	0.76	2	4	3
Overall							
	Heart Rate	60	80.00	12.65	61	118	
	Anxiety Level	60	3.12	1.36	1	7	

Route 2. Northern Route Round Trip

The minimum heart rate level for the case study five driver was recorded as 67, while the maximum was 74. The driver in case study five had an average heart rate of 70.43 with a standard deviation of 2.64 measured across seven measuring points along the departure and return route.

The minimum heart rate level for the case study six driver was recorded as 69, while the maximum was 118. The driver in case study six had an average heart rate of 95.00 with a standard deviation of 16.37 measured across eight measuring points along the departure and return route.

Lastly, case study seven driver's minimum heart rate level was recorded as 68 while the maximum was 88. The driver in case study seven had an average heart rate of 77.50 with a standard deviation of 6.61 measured across eight measuring points along the departure and return route.

Overall, all drivers' minimum heart rate level was recorded as 61, while the maximum was 118. The overall average heart rate level of all the drivers was 80.00, with a standard deviation of 12.65. We now analyse the full trip: the novice EV driver in case study six is described as having the highest average heart rate level (M = 95.00, SD = 16.37) while the lowest heart rate level was for the experienced ICE driver in case study one (M = 67.43, SD = 4.64). The second-ranked driver in terms of highest average heart rate was the case study two novice EV driver (M = 90.80, SD = 13.21), then followed by case study three driver (M = 78.10, SD = 5.86), followed by case study seven driver (M = 77.50, SD = 6.61), followed by case study four driver (M = 76.60, SD = 5.78), and lastly case study five driver (M = 70.43, SD = 2.64). These results are graphically represented in Figure A1 below.

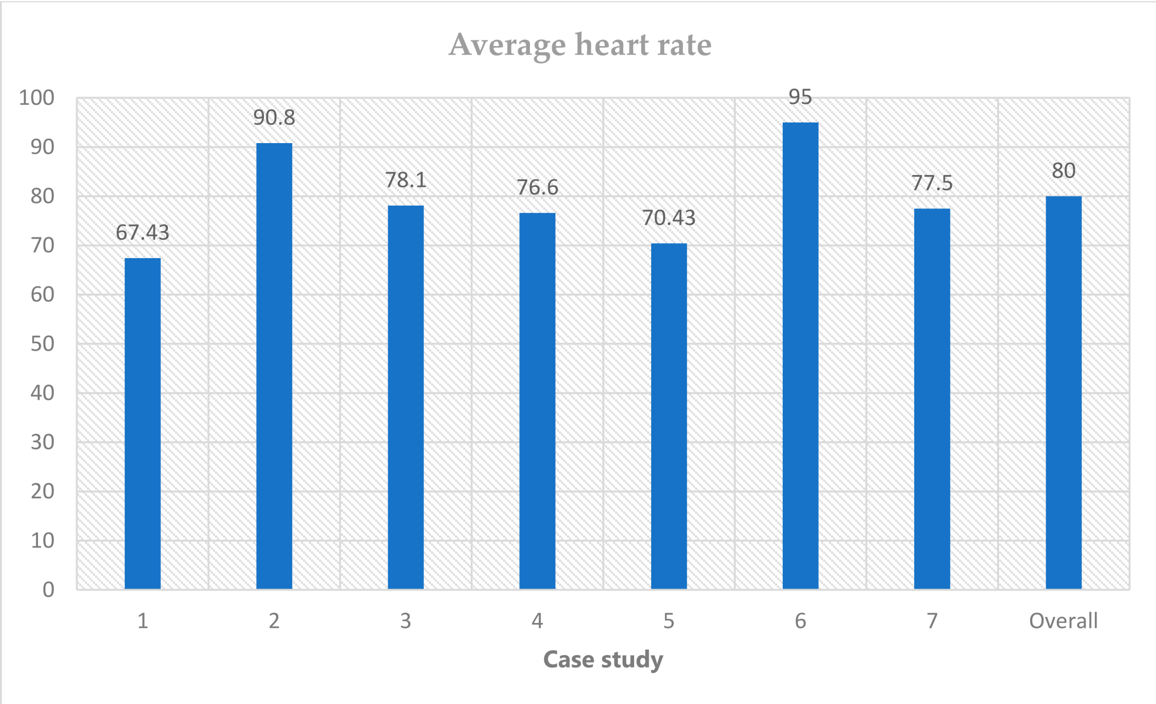

Figure A1. Average heart rate (BPM).

Appendix B.1.3 Anxiety Level Per Case Study

Additionally, by inspecting the results presented in Table A8, the minimum anxiety level for case study one driver was recorded as 1 while the maximum anxiety level was 2. The driver in case study one had an average anxiety level of 1.71 with a standard deviation of 0.48 calculated across seven measuring points along the departure and return route.

The minimum anxiety level for case study two driver was recorded as 2, while the maximum level was 6. The driver in case study two had an average anxiety level of 4.30 with a standard deviation of 1.34 calculated across ten measuring points along the departure and return route.

The minimum anxiety level for case study three driver was recorded as 2, while the maximum level was 4. The driver in case study three had an average anxiety level of 2.90 with a standard deviation of 0.56 calculated across ten measuring points along the departure and return route.

The minimum anxiety level for case study four driver was recorded as 2, while the maximum level was 4. The driver in case study four had an average anxiety level of 2.80 with a standard deviation of 0.63 calculated across ten measuring points along the departure and return route.

The minimum anxiety level for case study five driver was recorded as 1, while the maximum level was 2. The driver in case study five had an average anxiety level of 1.86 with a standard deviation of 0.38 calculated across seven measuring points along the departure and return route.

The minimum anxiety level for case study 6 driver was recorded as 2, while the maximum anxiety level was 7. The driver in case study 6 had an average anxiety level of 4.75 with a standard deviation of 1.67 calculated across eight measuring points along the departure and return route.

Lastly, the minimum anxiety level for case study seven driver was recorded as 2, while the maximum level was 4. The driver in case study seven had an average anxiety level of 3.00 with a standard deviation of 0.76 calculated across eight measuring points along the departure and return route.

Overall, the minimum anxiety level for all drivers was recorded as 1, while the maximum level was 7. The overall average anxiety level of all the drivers was 3.12, with a standard deviation of 1.36. In case study six, the novice EV driver had the highest average anxiety level (*M* = 4.75, *SD* = 1.67), while the lowest average level was for the experienced ICE driver in case study 1 (*M* = 1.71, SD = *SD* = 0.48). Additionally, the second-ranked driver in terms of highest average anxiety level was the case study two novice EV driver (*M* = 4.30, *SD* = 1.34), followed by case study seven experienced EV driver (*M* = 3.00, *SD* = 0.76), followed by case study three Novice EV driver (*M* = 2.90, *SD* = 0.56), then followed by case study four experienced EV driver (*M* = 2.80, *SD* = 0.63), and lastly, case study five experienced ICE driver (*M* = 1.86, *SD* = 0.38). The average anxiety level results are graphically represented in Figure A2 below.

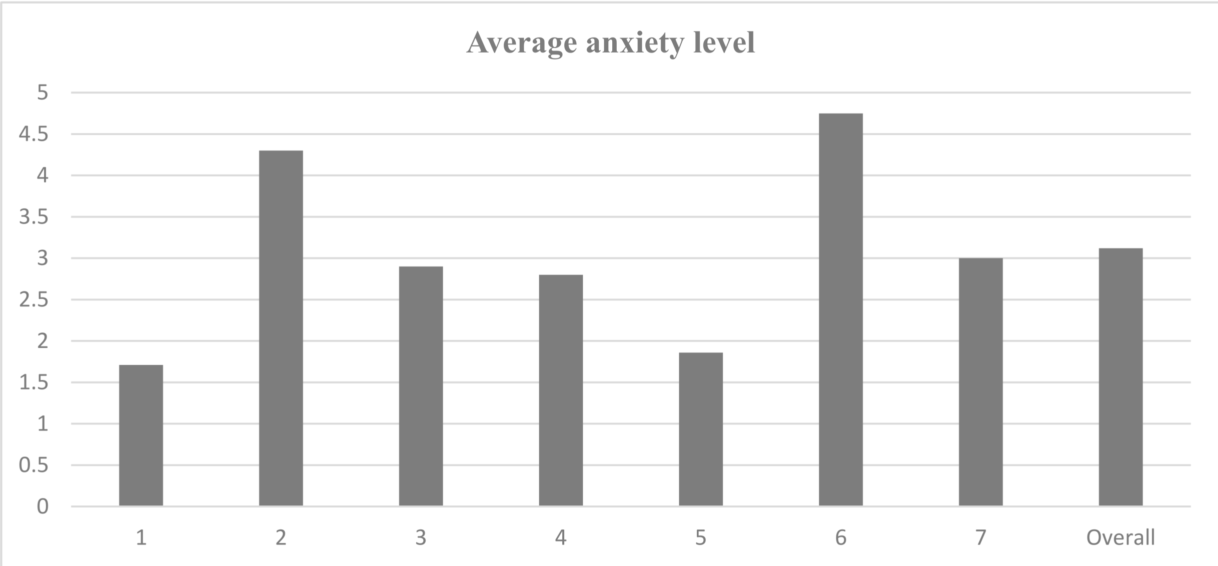

Figure A2. Average anxiety levels.

Appendix B.1.4 Descriptive Analysis Per Journey

We also conducted a descriptive analysis to examine the average heart rate and anxiety levels for each journey. The first route was covered by drivers in case studies 1, 2, 3, and 4, while the second route was covered by drivers in case studies 5, 6, and 7. We utilised the mean, standard deviation, minimum, and maximum statistics to conduct the analysis. The results obtained from the descriptive analysis are presented in Table A9 below.

Table A9. Descriptive Analysis of Study Variables Per Journey.

Journey		N	Mean	SD	Min	Max
1						
	Heart Rate	37	79.11	11.43	61	110
	Anxiety Level	37	3.03	1.21	1	6
2						
	Heart Rate	23	81.43	14.57	67	118
	Anxiety Level	23	3.26	1.60	1	7

Appendix B.1.5 Heart Rate Per Journey

Considering the results presented in Table A9 above, the minimum heart rate level for the first journey was 61, while the maximum was 110 among all drivers who completed route one. The average heart rate of all route one drivers was 79.11, with a standard deviation of 11.43 based on 37 measures. The minimum heart rate level for route two was 67, while the maximum was 118 among all drivers who completed route two. The average heart rate of all route two drivers was 81.43, with a standard deviation of 14.57 based on 23 measures. The descriptive results indicate that drivers in route two had a higher average heart rate than drivers who undertook route one. The main reason for this is that route one drivers started the journey with a full charge, whereas on route two, we purposely provided both ICE and EV drivers vehicles with just enough fuel or charge to make it to the mid-point stop at Rugby Services. We learnt from these results that lower fuel or charge levels significantly increased anxiety amongst the cohort of drivers in route two compared to the drivers in the route one study. The latter departed with a full tank of fuel or a fully charged battery.

Appendix B.1.6 Anxiety Levels Per Journey

Additionally, using the results presented in Table A9 above, the minimum anxiety level for the first journey was 1, while the maximum was 6 among all drivers who drove on route one. The average anxiety level of all route one drivers was 3.03, with a standard deviation of 1.21 based on 37 measures. Conversely, the minimum anxiety level for route two was 1, while the maximum level was 7 among all route two drivers. Additionally, the average anxiety level of all route two drivers was 3.26, with a standard deviation of 1.60 based on 23 measures. The descriptive results indicate that drivers in route two cohort had a higher average anxiety level than drivers of route one due to route two drivers starting with minimal fuel or charge to enable vehicles to reach the mid-way point.

Appendix B.1.7 Differences in Heart Rate and Anxiety Levels

The researcher investigated a significant difference in the heart rate and anxiety levels between route one and two drivers by employing a two-independent sample *t*-test analysis technique for the investigation and using a 0.05 level of significance for the test. The results of the analysis conducted are presented in Table A10.

Table A10. Results of Independent Samples Test (n = 1419).

Journey	T	Df	Sig.	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
1	0.689	58	0.493	2.33	−4.43	9.08
2	0.641	58	0.524	0.23	−0.50	0.96

Considering the *t*-test results presented in Table A10, both results for heart rate [t (58) = 0.689, p = 0.463, $p > 0.05$] and anxiety level [t (58) = 0.641, p = 0.524, $p > 0.05$] were established to be insignificant. The results established indicate that there is no statistically significant difference between the journey one drivers heart rate levels (n = 37, M = 79.11, SD = 11.43) and journey two drivers heart rate levels (n = 23, M = 81.43, SD = 14.57). Nevertheless, the results established indicate that there is no statistically significant difference between the route one drivers' anxiety levels (n = 37, M = 3.03, SD = 1.21) and route two drivers' anxiety levels (n = 23, M = 3.26, SD = 1.60). Therefore, based on these results, we have enough evidence to conclude that there is no significant difference in the heart rates and anxiety levels between route one and two drivers. This confirms that our matrix in Table 9 in the main body of text and Table A11 below, converting BPM to anxiety levels, is statistically correct.

Appendix B.1.8 Relationship between Heart Rate and Anxiety Levels

Based on the data collected, we examined a significant correlation between the drivers' heart rates and anxiety levels in the seven case studies. A 0.05 level of significance was utilised for the test. The results established and presented in Table A11 below show a significant correlation between the drivers' heart rate and anxiety levels, $\alpha = 0.05$, $r = 0.953$, $p < 0.05$. These results suggest a statistically significant strong positive relationship between the heart rate and anxiety levels of the drivers, confirming that as the heart rates of the drivers increase, so does their anxiety levels.

Table A11. Correlation Analysis Summary Results.

			1	2
1.	Heart rate	Pearson Correlation	1	0.953 *
		Sig. (2-tailed)		0.000
2.	Anxiety level	Pearson Correlation	0.953 *	1
		Sig. (2-tailed)	0.000	

*. Correlation is significant at the 0.05 level (2-tailed).

References

1. Hirst, D. *Electric Vehicles and Infrastructure*; House Commons Library: London, UK, 2020; pp. 1–31.
2. Bunce, L.; Harris, M.; Burgess, M. charge up then Charge out? Drivers' Perceptions and Experiences of Electric Vehicles in the UK. *Transp. Res. Part A Policy Pract.* **2014**, *59*, 278–287. [CrossRef]
3. Reeves, R.; Coaker, V.; Hendry, D.; Kerr, S.; Kyle, P. *Electric Vehicles: Driving the Transition: Fourteenth Report of Session 2017–19*; House Commons Libr.: London, UK, 2018; pp. 1–70.
4. Noel, L.; de Rubens, G.Z.; Sovacool, B.K.; Kester, J. Fear and loathing of electric vehicles: The reactionary rhetoric of range anxiety. *Energy Res. Soc. Sci.* **2019**, *48*, 96–107. [CrossRef]
5. Xu, M.; Yang, H.; Wang, S. Mitigate the range anxiety: Siting battery charging stations for electric vehicle drivers. *Transp. Res. Part C Emerg. Technol.* **2020**, *114*, 164–188. [CrossRef]
6. Chen, R.; Liu, X.; Miao, L.; Yang, P. Electric Vehicle Tour Planning Considering Range Anxiety. *Sustainability* **2020**, *12*, 3685. [CrossRef]
7. Chamberlain, K.; Al-Majeed, S. Standardisation of UK Electric Vehicle Charging Protocol, Payment and Charge Point Connection. *World Electr. Veh. J.* **2021**, *12*, 63. [CrossRef]
8. Rauh, N.; Franke, T.; Krems, J.F. Understanding the impact of electric vehicle driving experience on range anxiety. *Hum. Factors* **2015**, *57*, 177–187. [CrossRef]
9. Franke, T.; Rauh, N.; Günther, M.; Trantow, M.; Krems, J.F. Which Factors Can Protect Against Range Stress in Everyday Usage of Battery Electric Vehicles? Toward Enhancing Sustainability of Electric Mobility Systems. *Hum. Factors J. Hum. Factors Ergon. Soc.* **2016**, *58*, 13–26. [CrossRef]
10. Eisel, M.; Nastjuk, I.; Kolbe, L.M. Understanding the influence of in-vehicle information systems on range stress—Insights from an electric vehicle field experiment. *Transp. Res. Part F Traffic Psychol. Behav.* **2016**, *43*, 199–211. [CrossRef]
11. Tannahill, V.R.; Sutanto, D.; Muttaqi, K.M.; Masrur, A. Future vision for reduction of range anxiety by using an improved state of charge estimation algorithm for electric vehicle batteries implemented with low-cost microcontrollers. *IET Electr. Syst. Transp.* **2015**, *5*, 24–32. [CrossRef]
12. Faraj, M.; Basir, O. Range anxiety reduction in battery-powered vehicles. In Proceedings of the 2016 IEEE Transportation Electrification Conference and Expo (ITEC), Dearborn, MI, USA, 27–29 June 2016.
13. Sarrafan, K.; Muttaqi, K.M.; Sutanto, D.; Town, G.E. An Intelligent Driver Alerting System for Real-Time Range Indicator Embedded in Electric Vehicles. *IEEE Trans. Ind. Appl.* **2017**, *53*, 1751–1760. [CrossRef]
14. Tannahill, V.R.; Muttaqi, K.M.; Sutanto, D. Driver alerting system using range estimation of electric vehicles in real time under dynamically varying environmental conditions. *IET Electr. Syst. Transp.* **2016**, *6*, 107–116. [CrossRef]
15. SMMT. Vehicle Registrations: Electric Vehicle and Alternatively Fuelled Vehicle Registrations. 2019. Available online: https://www.smmt.co.uk/vehicle-data/evs-and-afvs-registrations/ (accessed on 18 January 2020).
16. International Energy Agency. *Global EV Outlook 2019 Scaling the Transition to Electric Mobiity*; IEA: Paris, France, 2019.
17. Biondi, E.; Boldrini, C.; Bruno, R. Optimal charging of electric vehicle fleets for a car sharing system with power sharing. In Proceedings of the IEEE International Energy Conference (ENERGYCON), Leuven, Belgium, 4–8 April 2016.
18. Pevec, D.; Babic, J.; Carvalho, A. A survey-based assessment of how existing and potential electric vehicle owners perceive range anxiety. *J. Clean. Prod.* **2020**, *276*, 122779. [CrossRef]
19. UK Government. Electric Vehicle Charging Device Statistics: October 2019. Available online: https://www.gov.uk/government/statistics/electric-vehiclecharging-device-statistics-october-2019 (accessed on 18 January 2020).
20. Becker, T.A.; Sidhu, I. Available online: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1048.8973&rep=rep1&type=pdf (accessed on 24 August 2009).
21. Saxena, S.; Gopal, A.; Phadke, A. Electrical Consumption of Two-, Three- and Four-Wheel Light-Duty Electric Vehicles in India. *Appl. Energy* **2014**, *115*, 582–590. [CrossRef]
22. Liu, J.H.; Meng, Z. Innovation Model Analysis of New Energy Vehicles: Taking Toyota, Tesla and BYD as an Example. *Procedia Eng.* **2017**, *174*, 965–972. [CrossRef]
23. Delbosc, A.; Ralph, K. A tale of two Millennials. *J. Transp. Land Use* **2017**, *10*, 903–910. [CrossRef]
24. Nicholas, M.; Hall, D.; Lutsey, N. Quantifying the Electric Vehicle Charging Infrastructure Gap across US Markets. *Int. Counc. Clean Transp.* **2019**, *20*, 1–39.

25. Talantsev, A. Who Gains and Who Loses in the Shift to Electric Vehicles: Impact Assessment through Multi-criteria Multi-stakeholder Analysis. *Procedia Environ. Sci.* **2017**, *37*, 257–268. [CrossRef]
26. Tarascon, J.M.; Armand, M. Issues and challenges Facing Rechargeable Lithium Batteries. *Nature* **2011**, *414*, 359–367. [CrossRef]
27. Assadian, F.; Mallon, K.; Walker, B. *New Energy Management Concepts for Hybrid and Electric Powertrains: Considering the Impact of Lithium Battery and Ultracapacitor A*; Intechopen: London, UK, 2018; pp. 1–15.
28. Chen, T.; Dai, L. Carbon Nanomaterials for High-Performance Supercapacitors. *Mater. Today* **2013**, *16*, 272–280. [CrossRef]
29. Xie, K.; Qin, X.; Wang, X.W.; Wang, W.; Tao, H.; Wu, Q.; Yang, L.; Hu, Z. Carbon Nanocages as Supercapacitor Electrode Materials. *Adv. Mater.* **2012**, *24*, 347–352. [CrossRef]
30. Bkrey, I.N.; Moniem, A.A. Flexible Laser Reduced Graphene Oxide/MnO2 Electrode for Supercapacitor Applications. *Int. J. Chem. Nucl. Mater. Metall. Eng.* **2014**, *8*, 893–899.
31. Zaid, R.M.; Chong, F.C.; Teo, E.Y.L.; Ng, E.-P.; Chong, K.F. Deduction of Graphene Oxide Nanosheets by Natural Beta Carotene and its Potential use as Supercapacitor Electrode. *Arab. J. Chem.* **2015**, *8*, 560–569. [CrossRef]
32. Yeh, M.H.; Lin, L.Y.; Li, T.J.; Leu, Y.A.; Chen, G.L.; Tien, T.C.; Hsieh, C.Y.; Lo, S.C.; Huang, S.J.; Chiang, W.H.; et al. Synthesis of Boron-Doped Multi-Walled Carbon Nanotubes by an Ammonia-Assisted Substitution Reaction for Applying in Supercapacitors. *Energy Procedia* **2014**, *61*, 1764–1767. [CrossRef]
33. Lu, X.; Wang, G.; Zhai, T.; Yu, M.; Xie, S.; Ling, Y.; Liang, C.; Tong, Y.; Li, Y. Stabilized Tin Nanowire Arrays for High-Performance and Flexible Supercapacitors. *Nano Lett.* **2012**, *12*, 5376–5381. [CrossRef] [PubMed]
34. Yoo, H.D.; Markevich, E.; Salitra, G.; Sharon, D.; Aurbach, D. In the Challenge of Developing Advanced Technologies for Electrochemical Energy Storage and Conversion. *Mater. Today* **2014**, *17*, 110–121. [CrossRef]
35. Prasad, R.V.; Devasenapathy, S.; Vijay, S.; Rao Vazifehdan, J. Reincarnation in the Ambiance: Devices and Networks with Energy Harvesting. *IEEE Commun. Surv. Tutor.* **2014**, *16*, 195–213. [CrossRef]
36. Knupfer, S.; Noffsinger, J.; Sahdev, S. *How Battery Storage Can Help Charge the Electric-Vehicle Market*; Mckinsey: New York, NY, USA, 2018.
37. SMMT. Electric Car Registrations Surge in August but It's a Long Road to Zero and Barriers Must Be Addressed. 5 September 2019. Available online: https://www.smmt.co.uk/2019/09/uk-electric-car-registrations-surge-in-august-but-its-a-long-road-to-zero-and-barriers-must-be-addressed/ (accessed on 23 May 2020).
38. US Department of Energy. *Vehicle Charging*; US Department of Energy: Washington, DC, USA, 2020.
39. Smith, M.; Castellano, J. *Costs Associated with Non-Residential Electric Vehicle Supply Equipment*; US Dep. Energy: Washington, DC, USA, 2015; pp. 1–43.
40. Statista. *Number of Electric Vehicle Charging Stations by Type in the United Kingdom (UK) from 2011 to 2019*; Statista: Haburg, Germany, 2020.
41. Lorentzen, E.; Haugneland, P.; Bu, C.; Hauge, E. Charging infrastructure experiences in Norway—The worlds most advanced EV market. In Proceedings of the EVS30 Symposium, Stuttgart, Germany, 9–11 October 2017.
42. Hildermeier, J.; Kolokathis, C.; Rosenow, J.; Hogan, M.; Wiese, C.; Jahn, A. Smart EV Charging: A Global Review of Promising Practices. *World Electr. Veh. J.* **2019**, *10*, 80. [CrossRef]
43. Zhang, B.; Niu, N.; Li, H.; Wang, Z.; He, W. Could fast battery charging effectively mitigate range anxiety in electric vehicle usage? Evidence from large-scale data on travel and charging in Beijing. *Transp. Res. Part D Transp. Environ. J.* **2021**, *95*, 102840. [CrossRef]
44. Santos, G.; Rembalski, S. Do electric vehicles need subsidies in the UK? *Energy Policy J.* **2021**, *149*, 111890. [CrossRef]
45. Vaismoradi, M.; Turunen, H.; Bondas, T. Content Analysis and Thematic Analysis: Implications for Conducting a Qualitative Descriptive Study. *Nurs. Health Sci.* **2013**, *15*, 398–405. [CrossRef]
46. Maguire, M.; Delahunt, B. Data Analysis: A Practical, Step-by-Step Guide for Learning and Teaching Scholars. *AISHE* **2017**, *8*, 3351–3364.
47. Deloitte. *Hurry Up and ... Wait the Opportunities around Electric Vehicle Charge Points in the UK*; Deloitte: New York, NY, USA, 2019; pp. 1–20.
48. Kuang, Y.; Chen, Y.; Hu, M.; Yang, D. Influence analysis of driver behavior and building category on economic performance of electric vehicle to grid and building integration. *Appl. Energy J.* **2017**, *207*, 427–437. [CrossRef]
49. Bashar, S.K.; Han, D.; Ding, E.; Whitcomb, C.; McManus, D.D.; Chon, K.H. Smartwatch Based Atrial Fibrillation Detection from Photoplethysmography Signals. In Proceedings of the 2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Berlin, Germany, 23–27 July 2019.
50. Raja, J.M.; Elsakr, C.; Roman, S.; Cave, B.; Pour-Ghaz, I.; Nanda, A.; Maturana, M.; Khouzam, R.N. Apple Watch, Wearables, and Heart Rhythm: Where do we stand? *Ann. Transl. Med.* **2019**, *7*, 417. [CrossRef] [PubMed]
51. Falter, M.; Budts, W.; Goetschalckx, K.; Cornelissen, V.; Buys, R. Accuracy of Apple Watch Measurements for Heart Rate and Energy Expenditure in Patients with Cardiovascular Disease: Cross-Sectional Study. *JMIR Mhealth Uhealth* **2019**. [CrossRef]
52. Khanade, K.; Sasangohar, F. *Efficacy of Using Heart Rate Measurements as an Indicator to Monitor Anxiety Disorders: A Scoping Literature Review*; Department of Industrial and Systems Engineering, Texas A&M University: College Station, TX, USA, 2017.
53. British Heart Foundation. Your Heart Rate. Available online: https://www.bhf.org.uk/informationsupport/how-a-healthy-heart-works/your-heart-rate (accessed on 18 April 2021).
54. Geethavani, G.; Rameswarudu, M.; Rameshwari Reddy, R. Effect of Caffeine on Heart Rate and Blood Pressure. *Int. J. Sci. Res. Publ.* **2014**, *4*, 1–2.
55. Zap-Map. UK Rapid Charging Live Database. Available online: https://www.zap-map.com/live/ (accessed on 19 November 2020).